ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. XV DECEMBER, 1920 NO. 8

A MICROSCOPIC STUDY OF VEIN QUARTZ.[1]

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INTRODUCTION.

The need of further knowledge of the characteristic occurrence of vein minerals is evident to all engaged in studies of ore deposits. In recent years ore minerals have received increasing attention due to the development of the reflecting microscope, whereas the gangues are, as a rule, slighted. The most prominent of all gangue minerals is quartz, yet microscopic characteristics of vein quartz have received little attention in the literature of ore deposits, although unusual structures and anomalous habits have been noted. The present study was undertaken with a view to describing the more common microscopic characteristics of vein quartz, and, wherever possible, to indicate the relation between physical conditions of genesis of the quartz and its microscopic structure.

The investigation has been confined to silica in quartz veins of hydrothermal origin. Magmatic, contact metamorphic, and replacement ore bodies were not included, nor were those formed by supergene action. Quicksilver deposits and siliceous sinters were also excluded. However, the general field of hydrothermal quartz veins was well represented in the specimens studied.

[1] Synopsis of a dissertation submitted to the Department of Geology of Stanford University for the degree of Master of Arts, and prepared under the supervision of Professor C. F. Tolman, Jr. To him and to Professor A. F. Rogers I am indebted for keen interest in the work, and for many helpful suggestions and criticisms.

The deeper seated class of veins was covered by specimens from West Australia; Juneau, Alaska; Cornwall, England; Homestake, South Dakota; Porcupine, Ontario; and from the California gold belt. Deposits formed near the surface under low pressure were represented by suites from Arizona, Colorado, Nevada, and Idaho—in the United States—and from Mexico, Japan, New South Wales, and New Zealand. In the following pages deposits of this type are frequently referred to as "superficial," to express their formation at shallow depths. With this explanation there should be no confounding with surficial and oxidizing action, or with supergene enrichment. In these latter connections "superficial" is not used in this paper.

Laboratory investigation consisted of an examination of the specimens of the Economic Geology and Mineralogy collections of the University; a study of about five hundred accompanying thin sections; and finally, the preparation and study of two hundred specially selected thin sections. To supplement laboratory work all available pertinent literature was scanned for descriptions of microscopic characteristics of quartz. With the exception of a text on the microscopic examination of ores by Berg,[2] in which there is a chapter devoted to hydrothermal deposits, the literature examined—publications of the United States Geological Survey, magazine articles, and general textbooks—contained only scattered descriptions of microscopic features.

The results of the investigation will be detailed in two parts: Part I. (*a*) Varieties of silica formed in hydrothemal vein deposits; (*b*) Crystallization of silica from the hydrogel condition; (*c*) Structures in quartz which has crystallized in free space. Part II. (*a*) Structures in replacement quartz; (*b*) effects of strain on quartz; (*c*) rearrangements of silica.

PART I.

VARIETIES OF SILICA.

Of the oxides of silicon—quartz, chalcedony, tridymite, cristobalite, and opal—only the first two are of importance as gangue

[2] "Mikroskopische Untersuchung der Erzlagerstatten," Berlin, 1915.

minerals in the deposits studied. Tridymite and cristobalite, the high temperature forms, do not occur in ordinary mineral veins. Opal is found in negligible amounts, and is not worth consideration as a type of vein silica in the deposits herein treated. It should be repeated, however, that quicksilver ores and siliceous sinters were not investigated.

Chalcedony.

The relations of chalcedony to quartz, and to other less common varieties of silica are not well defined. Ordinarily chalcedony may be distinguished from quartz by its cryptocrystalline aggregate structure, weak double refraction, and lower index of refraction. Another important characteristic is color. In thin section chalcedony often may be distinguished from clear quartz by a milky opalescence with reflected light, or by a brownish turbidity with transmitted light. Of course, these colors are variable, but some color—white, brown, or other—is always present in the hand specimen and nearly always visible in thin section. Except as compared with clear transparent quartz, however, distinction by this means may be misleading. Sometimes coarsely crystalline quartz, and often anomalous varieties, are turbid.

Cryptocrystalline aggregate chalcedony is the common type observed in mineral deposits, either as a vein mineral, or as a replacement of country rock forming the cherts, jaspers, or other forms, particularly abundant in limestone replacement ores. In the latter connection it is not here considered. As a fissure vein mineral it may occur as a filling, or as a replacement of wall rock fragments or of earlier minerals, especially of calcite. In some veins, alternating compact chalcedony and microcrystalline quartz present a minute banded structure, which is often intricately contorted. The peculiar shapes assumed may be called colloform, a name introduced by Rogers[3] to express combinations of spherical, botroyoidal, reniform, stalactitic, and mamil-

[3] "A Review of the Amorphous Minerals," *Jour. of Geol.*, Vol. XXV., 1917. p. 518.

lary forms. Colloform structures in silica are usually inherited from a gelatinous state. The chalcedony in these cases is a metacolloid,[4] as also is the microcrystalline quartz. Chalcedony of this character is shown in Plate XXI., *A, B.*

A less common form of chalcedony is shown in one band of Figs. *C* and *D,* Plate XXI. This is fibrous, with refractive index less than quartz, and optically negative, but with a maximum double refraction equal to quartz. The birefringence of fibers cut parallel to the length may vary from a maximum to a minimum. The photographs as a whole picture alternating encrustations of quartz and chalcedony.

Other fibrous forms of silica are sometimes encountered. These may be either optically positive or optically negative, and may have other distinguishing characteristics. However, they are not prominent hypogene gangue minerals and will not be further considered.

The present investigation indicates that cryptocrystalline and fibrous chalcedony are found only in those deposits formed near the surface. Chalcedony is characteristic of the colloform crustifications of some Tertiary bonanza type ores, but it does not occur in prominence in the deeper seated quartz veins such as those of the Mother Lode in California. Even where best developed in superficial gold and silver deposits, chalcedony is usually subordinate to quartz in importance.

Normal Vein Quartz.

Quartz is one of the minerals classed as "persistent" by Lindgren;[5] *i.e.,* it is formed under conditions ranging from igneous to surficial. Two types of quartz have been recognized: beta-quartz, which is stable from 575° C. to 800° C.; and alpha-quartz, which is stable below 575° C. Wright and Larsen[6] have shown

[4] A term proposed by Wherry (*Jour. Wash. Acad. Sci.,* Vol. IV., 1914, p. 112) and defined as "a substance which, though originally colloidal in character, has become more or less crystalline."

[5] ECON. GEOL., Vol. II., 1907, p. 122.

[6] "Quartz as a Geologic Thermometer," *Am. Jour. Sci.,* Vol. 177, 1909, p. 446.

that vein quartz is of the alpha type, *i.e.*, it was formed at a temperature below 575° C.

The dominant form of most idiomorphic vein quartz is a combination of the prism (m) and the rhombehedrons (r) and (z), often modified by subordinate faces. The characteristic habit is prismatic. This prismatic habit, together with irregular development of the rhombehedral faces and the presence of trigonal trapezohedrons, is considered by Wright and Larsen as indicative of the alpha form of quartz. Usually crystals are singly terminated, being attached at one end of the prism. The development is at right angles to the plane of attachment, or parallel to the prism. In aggregates, however, doubly terminated crystals are often found.

Variations in size are enormous, ranging from large crystals down to cryptocrystalline varieties comparable to aggregate chalcedony. In thin section cryptocrystalline quartz often appears to have unusually low birefringence, inconsistent interference colors, and uneven extinction, due to the overlapping of individuals. The degree of development of crystal form also is variable. In the more coarsely crystalline quartz, subhedral outlines are common. In thin section euhedral cross sections are far more frequent than euhedral parallel sections, because of the comparatively rare double termination. Crystal form in the finer grained quartz is rarer, and is absent in microcrystalline varieties.

It has been said that coarsely crystalline massive quartz is a characteristic of deeper seated veins, whereas fine quartz is apt to occur in those deposits formed near the surface. As a generalization this is true. In such ores as those from the Juneau district, Alaska; West Australia; California gold belt; and Porcupine district, Ontario, the typical vein quartz is coarsely crystalline. The quartz in deposits in Tertiary volcanics is often fine grained to microcrystalline, although these deposits exhibit wide variations in size as well as in structure.

Anomalous Quartz.

The following anomalies consist of abnormal habits of quartz in which the optical properties are those typical of ordinary quartz.

"Feather" Quartz.—The most common abnormality is a splintery or feathery appearance caused by slight differences in extinction position. In some cases zonal lines, irregular cavities, or minute inclusions accompany this development. The splinters or feathers may be a peripheral development about normal crystals (*A* and *D*, Pl. XXII.). In such cases both in the cross sectional and longitudinal views a clear core appears.

In some instances in which the arrangement may be interpretated the feathered quartz is developed approximately normal to the prism faces. Where there is no clear core the feathers or splinters may form a six-sided cross (Pl. XXII., *B*). In this case extinction is approximately simultaneous for all portions of the cross, while the intervening sectors have widely varying and usually indefinite extinction positions. Rogers[7] has described a similar anomaly from Rawhide, Nevada, in which, however, sectors are approximately equally developed (Pl. XXII., *C*). The extinction is in sets of alternate sectors, the extinction position for one set being approximately 10° from that of the other. Rogers[8] also mentions similar quartz occurring with pyrite, chalcopyrite, ilmenite, and titanite in apparently high temperature veinlets in a diabase near Weehawken, New Jersey. The veinlets were, however, probably formd near the surface, under comparatively little pressure.

Symmetrical development of the quartz splinters or feathers is the exception. The more typical appearance is illustrated by the lower crystal in Pl. XXII., *C*, and by Pl. XXII., *D*, and XXIV., *D*. In a report on Silvertown, Colorado, Ransome[9] pictures feathered quartz resembling Pl. XXII., *A*.

Anomalous quartz of this type is best developed in specimens

[7] Econ. Geol., Vol. VI., 1911, p. 795.
[8] *Idem*, p. 797.
[9] U. S. G. S. Bull. 182, Plate X.

of ores which have undoubtedly been formed in free space. Feathered edges or patches are frequent in the outer tips of comb quartz. The specimens from Rawhide, however, are a replacement of tuff, showing that the anomaly may be a replacement phenomenon.

Flamboyant Quartz.—The only other anomalous habit in quartz which is of importance is the "flamboyant." This has been described from Cripple Creek by Lindgren.[10] In this study it has been found in a few other localities, notably in specimens from the Talisman Mine, Karangahake, New Zealand. In these specimens the quartz occurs as a filling in breccia. Pl. XXII., *E*, shows flamboyant quartz which has developed from the wall of a small fissure. Pl. XXII., *F*, is a more highly magnified view. The chief characteristic of the anomaly is the radial optical structure. Lindgren has suggested that this structure is due to each grain being composed of submicroscopic radial fibers, a possibility emphasized by the radial lines of relief in Pl. XXII., *F*. In sections cut parallel to the *c* axis, the extinction is always parallel to these fine lines. In a cross section of a single flamboyant crystal, there are a large number of small areas with slight differences of extinction position. These areas are usually but not always, anhedral.

Flamboyant quartz reaches its best development as a crystallization into vugs, veinlets, or other open spaces. It is closely related to that type of comb quartz in which the individual prisms are grouped radially about a common center (Pl. XXIV., *C*). The only distinction is in the fineness of composition. In one case, distinct quartz prisms occur, while in flamboyant quartz the whole is made up of submicroscopic fibers. The relation of the two types sometimes appears in a single individual. As an example: the small flamboyant quartz crystal in Pl. XXI., *D*, is radially fibrous at its base, but has a gradually increasing definition of extinction sectors on approaching the top, which is separated into several segments, each with sharp extinction. One of these segments has pyramid terminations.

[10] U. S. G. S., Prof. Paper 54, p. 179.

As a crystallization from a colloidal gel flamboyant quartz may approach spherulitic form (Pl. XXI., *F*).

The anomalous habits in quartz above described are characteristic of many of the lower pressure ore deposits, but have not been observed in quartz which is considered to have been formed at intermediate or great depths. Their occurrence in prominence is indicative of origin at superficial depths, under conditions of low pressure.

Inclusions in Quartz.

The presence of inclusions is so characteristic of quartz that a brief generalization concerning their ordinary occurrence is warranted.

Inclusions usually consist of minute cavities containing gas, liquid, or liquid with a gaseous bubble. The shape of cavities may be somewhat circular, lenticular, or often extremely irregular. Cavities with crystal faces (*i.e.,* negative crystals) are frequently recorded, but in comparison to irregular vacuoles are rare. Minute shreds and dust like particles, too small to be identified, frequently occur as a contemporaneous development in quartz. Other enclosed substances are carbonaceous and organic material, and various minerals such as chlorite, and rutile.

Inclusions may be so numerous as to give a distinctly clouded appearance in thin section. They occur in irregular patches in a crystal, in tenuous or straight lines or surfaces, or in roughly parallel sets of planes (Pl. XXIII., *F,* and XXIII., *A*). When lying in planes, the loci would, of course, appear as lines in a thin section. Under the highest power lines do not appear to be due to cracks, but rather simply to a linear arrangement of separated vacuoles. Zonal effects are often seen, the zonal lines usually parallelling the truncating pyramid faces.

Although a majority of the lines of inclusions extend only to the contact of the neighboring crystal and here terminate, many pass from one crystal to the next without interruption. Most of these lines consist of separated cavities filled with liquid or gas, or both. In those coarse-grained quartz aggregates which are

conceived to be formed in free space, it is impossible that such lines develop at the same time as the crystals. Assuming that there is a period of time before the growing crystals touch each other, a structure pertaining to both crystals must be subsequent to their completion. On a genetic basis, such lines of inclusions are distinct from those of contemporaneous origin. They are epigenetic, following sub-microscopic cracks or directions of strain in the crystals. A characteristic epigenetic pattern of inclusions is discussed in Part II.

In certain ores, the arrangement is apparently dependent on some other mineral. In a Grass Valley ore Lindgren[11] pictures a roughly radial distribution about arsenopyrite. Inclusions in quartz from Butte sometimes conform to the boundaries of sulphides.[12] Schrader[13] describes quartz from Gold Road, Arizona, which is divided into sectors by the radial distribution of inclusions. This distribution is often associated with the anomalous habits in quartz previously described.

The chief microscopic structure dependent on the arrangement of inclusions is zonal enlargement.

Zonal Enlargement.

A growing quartz crystal will often register changes in the character of the precipitating solution. Silica deposited at one stage may contain much foreign matter, and at a later period may be entirely clear of it. Abrupt changes in the composition of the solutions may cause sharp growth lines, whereas gradual changes are often marked by indefinite zones of inclusions in the crystals. An example of zonal markings is shown in Pl. XXIII., *A*. In this specimen the inclusions are largely minute shreds which are too small to be identified.

A more common variety of zonal marking is one in which the zonal lines can only be seen by a difference in refractive index. Such markings are illustrated in Pl. XXIII., *B*, in which the thin

[11] U. S. G. S., 17th Ann. Rept., Pt. II., Plate IV.
[12] Weed, U. S. G. S., Prof. Paper 74, p. 72.
[13] U. S. G. S. Bull. 397, p. 172.

section is thrown slightly out of focus to bring out the relief. These layers may be microscopic or submicroscopic layers of chalcedony which has been deposited upon the quartz in crystallographic continuity.

Zonal markings may occur in any quartz which has developed through the agency of discontinuous or varying solutions, but these lines are characteristic only of quartz which has developed in free space. Pl. XXI., *A*, and XXIV., *E*, show the same phenomenon in comb quartz and in a filled vug.

Secondary Enlargement and Phantom Veinlets.

A phenomenon allied to zonal growth is the secondary enlargement of crystal fragments. In its common form, this phenomenon is illustrated by Pl. XXIII., *E*, which shows a quartz fragment in tuff which has selected material from solutions and added it on in crystallographic orientation. Unique veinlets, which are not infrequent in California gold quartz, are produced by the same process. These consist of cemented fractures in massive quartz, in which the clear cementing material contrasts with the turbid older quartz. The veinlets are therefore easily seen by ordinary light. The introduced material, however, has been deposited in perfect orientation with each fractured crystal which it cements, and under crossed nicols the veinlet disappears. These veinlets, which have been called "phantom" by Tolman,[14] are illustrated in Pl. XXIII., *C, D*. Notice that one of the older crystals is slightly offset by a fracture.

GEL STRUCTURES.

Micro-botryoidal and micro-mamillary structures frequently appear in thin sections of vein material from quartz veins of the superficial type. Lindgren[15] has described micro-reniform structures in breccia cement, and banding simulating "Liesegang rings," in jasperoid from Tintic, Utah.

[14] Private Report. This use of "phantom" has been adopted as expressive of the disappearing character of the veinlet. Obviously it differs from mineralogical usage.

[15] Econ. Geol., Vol. X., 1915, pp. 225–240. U. S. G. S., Prof. Paper 107.

Such structures in quartz are unlike those usually associated with direct crystallization from aqueous solution or metasomatic replacement. They do resemble, however, structures either assumed by hydrogel minerals[16] or caused by diffusion and rythmic precipitation through colloidal media.[17] Megascopic diffusion banding as a weathering phenomenon is often pictured, as in the recent Ray-Miami paper by Ransome.[18] As a contact metamorphic phenomenon it has been described by Knopf.[19]

Gel structures may be classified under three headings:

1. Those assumed by colloidal and metacolloidal substances in free space.

2. Those due to diffusion and rythmic precipitation throughout a gel mass.

3. Those due to the segregation of impurities by crystallization.

On a microscopic scale distinct diffusion banding was not observed in vein quartz, nor was segregation of impurities by crystallization positively identified. The colloform structures are, however, not infrequent.

Structures of this type may be retained by: (1) A crystallization of the silica gel to chalcedony or quartz independently of the structure of the gel, which is outlined by impurities; (2) crystallization of silica of different varieties or grain conforming to the structure.

The first case is illustrated by Pl. XXI., *E, F.* The microbotryoidal outlines are preserved in the flamboyant, often spherulitic, quartz, which, however, is independent of the gel structure.

Pl. XXI., *A* and *B,* picture the second method of preservation. This is a colloform crustification on the wall of a veinlet. A portion of the country rock appears at the bottom of the photograph. The crosscutting veinlets are of later origin. In this

[16] A. F. Rogers, "A Review of the Amorphous Minerals," *Jour. of Geol.,* Vol. XXV., 1917, p. 518.

[17] Liesegang "Geologische Diffusionen," 1913. Review by A. Knopf in Econ. Geol., Vol. VIII., 1913, p. 804.

[18] U. S. G. S., Prof. Paper 115, Plate XIV.

[19] U. S. G. S. Bull. 358, Plate IV.

case microcrystalline quartz and chalcedony appear next to the wall, with later cryptocrystalline aggregates of quartz, chalcedony, and adularia of varying grain.

Gel deposition may alternate with crusts formed by direct crystallization. Some of the bands in Pl. XXI., *C*, are thought to be a result of gel conditions, whereas one, and probably two, layers of quartz were formed by direct crystallization from solution.

The distinguishing feature in crustification is a predominant direction of growth. Ordinary crustified quartz has a tendency to prismatic development at right angles to the plane of attachment; quartz crystallizing from a siliceous gel usually resembles the fine-grained replacement type in which crystallization starts from a large number of centers, or else is a spherulitic, or other anomalous variety.

Gel structures and crystallization from colloidal conditions should not be confused. The foregoing gel structures in vein quartz have only been found in material from veins of the superficial type. Much or all of the quartz next to be described, however, may have crystallized from colloidal suspensions,—a most common condition for the transportation of silica.

STRUCTURES IN QUARTZ CRYSTALLIZED IN FREE SPACE.

Interlocking Granular Structure.

Assumptions of a characteristic mode of occurrence of vein quartz are not uncommon in the literature of ore deposits. Probably the most frequent reference is to the "interlocking anhedra typical of vein quartz." Quartz conforming to this brief description is shown in Pl. XXIII., *F*. This texture, it is true, is characteristic of certain veins, and is a result of the mutual interference of crystals during growth. It may also be formed in replacements by quartz, as a result of recrystallization under pressure, in metamorphic quartzites, etc. It is here considered in relation to vein filling.

A granular, subhedral structure in quartz is the microscopic

expression of coarsely crystalline massive quartz. Such quartz is most representative of the deeper zones. Its chief characteristics are: (1) absence of predominant direction of growth; (2) the normality of the individuals (anomalies are extremely rare); (3) uniformity of structure throughout the vein; (4) and usually, absence of other gangue minerals in prominence.

In many specimens of massize quartz a general even grain and even distribution of larger and smaller crystals is noticeable. Other specimens, especially those from the higher temperature veins which approach pegmatites in character, show great variations in the size of their constituent crystals. In the deeper seated type of veins as a class, however, there is a uniformity of structures throughout the vein, and a monotony of vein filling which is not typical of veins formed near the surface. In the superficial type of ore deposits in which fissure filling is prominent, the striking characteristic is the lack of uniformity of development of the constituent crystals and therefore of microscopic structure.

In thin sections of massive quartz there are all gradations from interlocking anhedra to mosaics of well developed crystals. In many cases, there is no suggestion of prismatic development or other crystal form. Again, the structure may be an aggregate of anhedral and subhedral crystals, as in the typical California gold quartz. In other cases instead of interstitial spaces being filled with smaller quartz, the major crystals fit together snugly and in places are roughly dove-tailed into one another. Often a large crystal incloses an earlier prism (Pl. XXIV., *A*).

The massive vein quartz just described forms a rather distinct type usually associated with the deeper seated and often remarkably persistent veins. In the erratic fissures of the superficial deposits, quartz deposited in free space is drusy, crustified and banded, and variable in size and habit. Thin sections of quartz from these deposits often show a combination of several microscopic structures.

Crustification Banding.

Good microscopic examples of banding by crustification are not often found, however common the phenomenon may be in cavity fillings. Layers are usually so coarse as to occupy the width of a thin section. Where two bands or more do appear, the microscope will often bring out the minor irregularities rather than the general sequence of deposition. An unusually good example of crustification on a microscopic scale is shown in Pl. XXI., *C*. The banding by quartz and chalcedony has been partially destroyed by rearrangements of silica.

A megascopically fine-grained crustification is shown in Pl. XXIV., *B*, consisting of a band of coarse quartz between fine-grained quartz-adularia aggregates. The direction of crustification is indicated by the crystal terminations in the quartz, which project into the younger material.

In open fissures crustification may occur as a symmetrical banding from both walls of a fissure, or may develop from one wall only. Concentric crustification may take place in rounded cavities, in stalactites, etc. Concentric crustification in breccias produces "cockade" structure. Spheroidal quartz, an unusual variety of crustification, has been described by Purington.[20]

Crustified quartz may be irregularly interlocking, drusy, or arranged in "combs."

Cockade Structure

The occurrence of entirely isolated fragments of country rock in breccia is beyond dispute. When these fragments are surrounded by concentric crusts of quartz, the "cockade" structure is produced. The phenomenon has been noted many times and, probably as much as anything else, has given rise to discussion of the force of crystallization of growing crystals. Taber[21] reviews this phenomenon in a recent paper on the mechanics of vein formation. Separation of fragments in loose breccia by the

[20] Preliminary Report of the Mining Industries of the Telluride Quadrangle, Colorado. U. S. G. S., 18th Ann. Rept., Pt. III., p. 798.

[21] "The Mechanics of Vein Formation," Bull. A. I. M. E. No. 140, 1918, p. 1205.

force of growing crystals is a perfectly conceivable process, and conveniently explains otherwise difficult structures. In this connection, it should be said that replacement of the included fragments along edges also will accomplish their isolation. This replacement may proceed so evenly from all sides that the angularity is preserved. When the replacement is by quartz which closely simulates that originally cementing the fragments the result is a breccia of angular fragments separated by quartz which apparently has forced them apart.

However, replacement cannot account for the most typical cockade structures, in which quartz prisms bristle from all surfaces of a fragment. Such cases are believed to be due to a force exerted by the crystals in growth. On a microscopic scale, cockade structure has not been observed.

Comb Quartz.

Comb quartz refers to the growth of parallel prisms of quartz into free space and normal to the wall to which they are fixed. In thin section this structure is easily recognized. Under crossed nicols the prisms in a section of a veinlet often will extinguish at approximately the same instant (Pl. XXI., *B*). When the wall is uneven, the prisms sometimes interfere irregularly or often form fan-shaped groups (Pl. XXIV., *C*). In this case a sector of the veinlet is composed of several semicircular segments of long radius, the crystals of each segment extinguishing in sequence, due to the radial arrangement. Comb quartz crystals often have a tapering base or are attached to older crystals. Prisms growing into a veinlet from a small base have a tendency to increase in width at their free ends, and thus to crowd out a number of their neighbors. This is shown in Pl. XXIV., *D*.

Quartz in Small Cavities.

In cavities which are small in comparison to the crystals within them, prisms developing in various directions interfere. On complete filling the quartz forms an irregular mosaic and rarely has crystal outlines. As in other quartz which develops in free

space, however, it often shows phantom crystal faces (Pl. XXIV., *E*).

Drusy Quartz.

Intricately interlocking structure is quite characteristic of the delicate drusy quartz often found in superficial veins. Pl. XXIV., *F*, pictures quartz of this type. A retiform appearance approaching the prismatic replacement quartz structure is often noted. The most characteristic feature of this drusy quartz is a radial development of crystals about a center, or a central line, or a crustification from both sides of a thin medial plane. The center, central line, or medial plane, usually appears as a finer-grained quartz. This feature is shown in Pl. XXIV., *F*.

Spheroidal Crystallization.

Spheroidal crystallization of quartz has been noted by Purington[22] and Ransome.[23] Purington describes specimens which "show a nucleus composed of saccharoidal quartz" from which "radiate quartz crystals perhaps two inches in length." "These crystals mutually interfere with one another, and the ends closely interlock with the ends of other and similar crystals composing other spheroids."

In appearance the spheroidal quartz is allied to the roughly radial grouping in drusy quartz on the one hand, and to cockade structure on the other. However, spheroidal crystallization about a minute foreign particle, or a nucleus of saccharoidal quartz, does not parallel crystallization about the fragments of clastic origin essential to cockade structure. The kernels of pyrite (from which the quartz prisms radiate in a specimen from Silver City, Nevada) or the saccharoidal quartz described by Purington, were not detached from the vein walls, nor are they brecciated fragments of a former vein. The phenomenon is not, then, genetically related to "cockade" structure.

In the extreme of the drusy structure, the quartz may crystal-

[22] *Loc. cit.*, p. 798.

[23] "A Report on the Economic Geology of the Silvertown Quadrangle, Colorado," U. S. G. S. Bull. 182, 1901, p. 91.

lize in branching coral-like forms. The delicate, slightly supported structures are the nearest approach to true spheroidal crystallization, in which the particle to which the quartz is attached is at the center of the structure. Spheroidal quartz is, therefore, an extreme variety of the drusy development. Its crystallization may be conceived to have occurred about minute particles, or other centers of crystallization, distributed throughout a viscous liquid.

Anomalous habits of quartz frequently occur in crustifications, combs, and druses. A comb quartz individual is sometimes composed of bundles of very slender rod-like prisms, an approach to the structure of flamboyant quartz. Unusually long crystals often diverge into two or more segments with slightly varying extinction positions. Near the point where the difference in orientation begins, a corrugated appearance of the quartz may be apparent, resembling the anomalous feathery extinction previously described. As is shown in Pl. XXIV., *C*, inclusions are apt to occur at such points. The typical anomalous habit in comb quartz is shown in Pl. XXIV., *D*.

The structures described above have been those identified with filling in open spaces, the granular, hypidiomorphic texture being associated with deeper seated veins; and the crustifications of various types with the more superficial veins.

SUMMARY OF PART I.

Chalcedony and quartz are the only forms of silica of importance in the fissure veins within the scope of this investigation. Chalcedony is definitely restricted to a development under conditions of low temperature and pressure. Except as a late accessory it is not found in veins of deeper seated origin.

Coarse-grained normal quartz cannot be assigned to any particular condition of formation. Normal quartz *individuals* are persistent throughout all ranges of ore deposition. The anomalous varieties of quartz, feathered and flamboyant quartz, have been found only in deposits formed under conditions of low pressure. In these deposits the anomalies may be accessory or very prominent; in deeper seated veins they are rarely found.

In the deeper seated quartz veins the characteristic vein filling consists of an interlocking aggregate of normal quartz crystals. The structure is uniform throughout the vein. The superficial type of vein is characterized by its diversity of structure. Crustification involving banded, comb, cockade, and spheroidal structure, and colloform structures in microcrystalline quartz and chalcedony, are typical of the lower pressure class of veins. They are not characteristic and in fact almost never present in veins formed at greater depths.

In brief, the real difference in microscopic structure between deep seated and shallow veins is in the uniformity displayed. In one case, a single thin section of vein material may typify the vein; in the other, a large suite of specimens may be inadequate.

In the preceding discussions vein deposits have been divided into but two divisions: (1) those formed at shallow depth; and (2) those formed at greater depth. Under the latter class would fall Lindgren's[24] "deposits formed at intermediate depths" and "deposits formed at high temperatures and pressures." The microstructure of vein quartz is about the same for these types. The study was not extensive enough to warrant separating high temperature quartz from intermediate temperature quartz on the basis of its microscopic structure. Pegmatites and magmatic quartz veins such as those of the Silver Peak quadrangle in Nevada, described by Spurr[25] were not studied.

PART II.

A MICROSCOPIC STUDY OF VEIN QUARTZ.

In Part I. were described the ordinary forms of chalcedony and quartz, gel structures, and structures in quartz which has crystallized in free space. Part II. considers typical replacement quartz, replacement structures in fissure veins, and effects of pressure on quartz.

[24] "Mineral Deposits."
[25] U. S. G. S., Prof. Paper 55, 1906.

REPLACEMENT QUARTZ AND LAMELLAR STRUCTURE.

The importance of metasomatism in fissure veins is, of course, subordinate to its rôle in the formation of the great replacement ore bodies. Even in massive fissure fillings, however, replacement phenomena may usually be noticed, while in the brecciated and sheeted zones common in the Tertiary flow rocks, replacement, cementation, and encrustation are inseparable.

In an early paper, Lindgren[26] discussed metasomatic processes in fissure veins, describing the important metasomatic minerals and classifying veins according to the processes. Criteria for the recognition of replacement ore-bodies have been summarized by J. D. Irving.[27] Certain of the criteria advanced in these papers are applicable to microscopic study. In brief, these are:

1. The distinct alteration of well defined crystals, as in the sericitization of feldspar.

2. Sharply defined crystals of the secondary mineral embedded in the primary, as in the tourmalinization of quartz; or completely euhedral crystals developing in country rock.

3. Retention of the original structure of the mineral or rock replaced. In the proof of replacement by quartz, this item is of more importance than the two preceding.

Irving's fifth point, *absence of crustification,* must be applied with as much care in microscopic work as in the study of the larger features of ore-bodies. There can be no disagreement with his statement, "crustification, if present, is a definite evidence of the formation of ores in an open cavity, but its absence by no means proves the formation of a deposit by replacement."[28]

On a microscopic scale, true banding by deposition is rare. The comb structure in quartz, however, is not uncommon, and may usually be taken as an indication of original deposition in open spaces.[28a] In typical crustification there should be a sharp

[26] *Trans. A. I. M. E.,* Vol. 30, pp. 578–692.

[27] ECON. GEOL., Vol. 6, 1911, pp. 527–561, 619–669.

[28] *Loc. cit.,* p. 652.

[28a] Lindgren ("The Gold and Silver Veins of Silver City, De Lamar, and Other Mining Districts in Idaho," U. S. G. S., 20th Ann. Rept., Pt. III., p. 186) has described replacement comb quartz, but this is very unusual. Such

line of separation between the encrusting material and the wall rock. In contradistinction, replacement quartz crystals pierce the replaced material in an uneven line. In the typical replacement veinlet which develops along a submicroscopic crack, the quartz individuals frequently occupy the entire width of the veinlet, and except in those cases in which the boundaries of the veinlet are determined by other factors (Pl. XXV., *F*), project to varying depths into the wall rock (Pl. XXVIII., *A*). These criteria, however, are not always satisfactory. A single quartz crystal may extend from one side of an open veinlet to the other, while the original sharp line between encrusting and encrusted material is usually obliterated by replacements or rearrangements of silica. Replacement and encrustation are often so closely associated that there is great difficulty in distinguishing the effects of one from those of the other.

Anhedral Replacement Quartz.

In veinlets of anhedral crystals the texture of the quartz alone will not distinguish between origin by replacement or filling. By far the largest part of replacement quartz is, however, the finely crystalline to microcrystalline aggregate of interlocking anhedra typical of limestone silicification. In thin section the very fine-grained replacements present the salt and pepper effect shown in the breccia fragments of Pl. XXV., *A*. Under high magnification, grains often appear to have uneven, washed-out interference colors, and indistinct extinction, due to the overlapping of individuals. In replacements of rocks where there is variation in the character of the original constituents, the grain of replacing silica may change according to the particular portion of rock attacked. Thus feldspar silicified in a tuff may be replaced by coarser grained quartz than the ground mass.

The same variations in grain which distinguish features within

quartz must have taken its first orientation into comb arrangement under conditions at least simulating growth in free space; *i.e.*, a definite wall to which the crystals are attached and from which they develop in parallel position. Later growths by replacement would still retain the structure.

a silicified rock may also reveal entirely silicified fragments in a quartz cemented breccia. Pl. XXV., *A*, is of silicified dacite in breccia ore from Goldfield. However, distinct variation in grain may be temporary in such cases. In Pl. XXV., *A*, the silica of the fragments is being rearranged to more nearly resemble the cementing material. Such rearrangement of silica will be referred to later.

Retiform Structure.

In perhaps the majority of instances, replacement quartz is entirely anhedral, occasionally with ragged dentate borders (Pl. XXV., *C*). It may, however, develop the crystal forms shown in Pl. XXV., *B*, in which the quartz is replacing calcite. When silicification starts simultaneously at a large number of crystallization centers throughout a mass, euhedral quartz prisms with double terminations may develop. When near completion, such development produces an interlocking retiform or netlike aggregate of subhedral and euhedral prisms, some of which have double terminations and hexagonal outlines. This method of silicification in limestone has been described by Spurr,[29] and later pictured by Lindgren.[30]

On complete silicification the net-like appearance is less pronounced. Pl. XXV., *D*, pictures subhedral replacement quartz crystals which have developed at different points in calcite, and now interfere to some extent. In the vein material studied, a distinct retiform structure by replacement was not observed.

Silicification starting simultaneously at many places throughout a mass is probably just as common as silicification which advances as a wave, but the quartz individuals formed are usually anhedral. Only rarely do the isolated euhedral prisms necessary for a retiform structure develop. It should be noted that the presence of a doubly terminated quartz crystal does not in itself prove replacement, for these are not uncommon in quartz developed in free space.

[29] "Geology of the Aspen Mining District, Colorado," U. S. G. S. Mon. 31, pp. 218–219.

[30] "Metasomatic Processes in Fissure Veins," *Trans. A. I. M. E.*, Vol. 30, 1900, p. 628.

Inherited Structures.

Occasionally the outline of the quartz is derived from the original structure of the mineral replaced. For instance, in some lamellar quartz the structure is preserved due to the initial growth of quartz along certain crystallographic directions in calcite. This quartz develops in rectangular, often greatly elongated pattern, with straight edges. Later the replacement may proceed throughout the calcite in anhedral grains, but the structure is preserved by the quartz plates (Pl. XXV., *E*).

Lamellar structure may be a pseudomorph after other minerals, especially barite. The most important example of an inherited structure in vein quartz, however, is lamellar structure after calcite. This merits separate description.

Lamellar Quartz.

Lamellar quartz, pseudomorphic after calcite, is a characteristic of many deposits of the superficial type. In 1900 Lindgren[31] described lamellar quartz from De Lamar, Idaho. Schrader[32] has given details of the replacement in specimens from Jarbidge, Nevada, while Knopf[33] has illustrated lamellar calcite in process of replacement by quartz.

In the suite of specimens examined during this study are examples of lamellar quartz from De Lamar; Jarbidge; Gold Road, Arizona; and Bodie, California. An enumeration of the megascopic characteristics of this quartz is an unnecessary repetition of the descriptions by Lindgren and Schrader. Specimens from Bodie, California, are of interest in that the calcite occurs in broad and remarkably thin plates parallel to the basal pinacoid. This habit, on a smaller scale, is prominent in material from Gold Road, Arizona. The original calcite does not now occur in De Lamar and Jarbidge, so that its character must be inferred from the pseudomorph.

[31] U. S. G. S., 20th Ann. Rept., Pt. III., 1900.

[32] U. S. G. S. Bull. 497, 1912, pp. 54, 55.

[33] "Ore Deposits of the Helena Mining Region, Montana," U. S. G. S. Bull. 527, 1913, Plate III. and IV.

Under the microscope, the larger features of the lamellar structure are reproduced on a minute scale. The low magnification view, Pl. XXVI., *A,* brings out the fan-like arrangement of plates, triangular areas, and the fragility of the structure in thin section.

In some previous descriptions emphasis has been placed on the replacement as proceeding along the cleavage planes of the calcite. Pseudomorphism dominated by the rhombehedral cleavage would give a rhombehedral arrangement of laminæ, which sometimes is seen. However, the arrangement of laminæ in most lamellar quartz does not recall cleavage directions, but rather a bladed structure in the calcite, or a replacement along a single set of parallel planes, not a system of intersecting planes.

This structure in the calcite is the platy habit parallel to the basal pinacoid, while the direction of replacement is controlled by the basal parting, which is developed in far more prominence than the cleavage. Pl. XXV., *F,* pictures calcite being replaced along parting planes. Replacement proceeds along these planes more easily than normal to them. There are probably microscopic sheeted zones, caused by unusually prominent parting, along which replacement is rapid, whereas transverse to the walls of these zones it is slow. Under such conditions the quartz individuals would develop in the rectangular forms shown in Pl. XXV., *E.*

Encrustation and solution accompany replacement in this pseudomorphism. Often quartz combs fill spaces in cellular calcite. In other cases a mesh of siliceous laminæ is exposed by the solution of the unsilicified portions of the calcite. Lines of inclusions are often more important than the shape of quartz grains in indicating the structure. In some thin sections adularia, which often occurs with the quartz, is confined to the replaced calcite laminæ and is not found in the encrusting comb quartz. On the other hand, in Pl. XXVI., *A,* it is almost lacking in some of the delicate ribs, and is absent in the coarser quartz filling, but is abundant throughout the rest of the section. Corresponding variations in relief may be seen in the photograph. Such features help to bring out the structure.

"Radial" Quartz.

An allied pseudomorphic structure, "radial" quartz, is described by Lindgren[34] from the Republic District, Washington. The lamellar habit of the original mineral, probably calcite, is indicated by the dark lines of inclusions in Pl. XXVI., *B*. Microcrystalline adularia is abundant, and is often segregated along the radial lines. The quartz, though occasionally rectangular as pictured in Pl. XXV., *E*, is usually anhedral. A similar structure in quartz and adularia occurs in some of the material from the United Eastern Mine, Oatman, Arizona. In this case, it is distinctly a pseudomorph after bladed calcite.

In some instances, one encounters quartz, of which association proves it to be a replacement type, and yet which has a habit that cannot be explained by any one of the known processes of replacement. To illustrate this, the following example is introduced.

Anomalous Habit in Replacement Quartz.

In a specimen of quartz-pyrite vein material from Shasta Co., California, quartz occurs in a finely columnar habit (Pl. XXVI., *C*). Crystals may be roughly rectangular and are often curved or bent. The columns may be either positively or negatively elongated. In Pl. XXVI., *C*, the quartz is shown standing normal to a pyrite veinlet. In some places quartz of this character forms veinlets cutting through the sulphide. In these cases it is truly fiber-like, resembling chrysolite veinlets in serpentine. In this particular specimen the quartz is apparently a secondary enlargement of older crystals at the expense of pyrite.

The same or a very similar form of quartz has been described by Young[35] from the Witwatersrand conglomerates. This unusual habit is also characteristic of certain pyritized schists of the California foothill copper belt[36] (Pl. XXVI., *D*). In the schists an explanation of origin for the quartz involving replacement of pyrite is not satisfactory, for the cubes are often fresh;

[34] U. S. G. S. Bull. 550, 1914, p. 147.
[35] *Trans. Geol. Soc. South Africa*, Vol. X., 1907, p. 18, 19.
[36] C. F. Tolman, Jr. Personal communication.

nor is there any evidence that the quartz is pseudomorphic after some other mineral. Occasionally this habit appears to be a longitudinal shattering of older grains, in which case it resembles the shredded quartz mentioned a little later. As a rule, however, the quartz shows no suggestion of having been strained after crystallization. Its semi-fibrous form is a growth habit. Taber[37] considers a fibrous structure an evidence of crystallization under pressure, in which the growing mineral has made a place for itself by mechanically displacing the adjoining wall rock. Sufficient data has not been secured either to accept or reject this theory as an explanation of the phenomenon here considered.

PRESSURE PHENOMENA.

Distortion or granulation is the usual result of pressure which exceeds the elastic limit of the mineral strained. Distortion is most noticeable by a strained extinction under crossed nicols of the microscope. The strain shadows results from a disturbance of the optional continuity of the crystal. They are characteristic of quartz which has been subjected to heavy pressure. Except in so far as they are mentioned on a later page, they will not be discussed.

Inclusion Pattern by Strain.

In some thin sections cut from quartz from the Allegheny and Grass Valley districts in California, inclusions are arranged in parallel planes or intersecting sets of parallel plants (Pl. XXVI., *E*). Each grain usually has its individual inclusional pattern which is confined to that crystal. Contemporaneous development cannot account for such an arrangement of inclusions. Strain, however, has been shown to develop this pattern.

After subjecting a quartz crystal to a pressure of 34,000 pounds, Adams[38] found that, though still coherent, the crystal "was traversed by a large number of cracks following directions approximately parallel to the rhombehedron faces, many of them

[37] A. I. M. E. Bull. 140, 1918, pp. 1211–1213, 1221.

[38] *Jour. of Geol.*, Vol. 18, 1910, p. 510.

not passing completely through the crystal, but running along a certain distance and being intersected by others crossing them." Whether this cracking is due to the rarely observed rhombehedral cleavage of quartz or to shear planes which may develop in any rigid body under pressure, is uncertain, as the paragraph goes on to say.

Since the grid of inclusions is a property of the individual crystal, and not a pattern extending over a number of crystals, it is probable that the rhombehedral cleavage is the controlling factor in this orientation. However, the development of this inclusion pattern is probably not by actual fracturing and subsequent healing, an origin assumed by Ferguson[39] for inclusions in the Allegheny district quartz. Judd has shown that rows of bubbles may be developed along directions of shearing in minerals without, or prior to, faulting. In the slides examined there is nothing to indicate that the mineral has fractured.

The latticed structure shown by inclusions may sometimes be seen under crossed nicols (Pl. XXVI., *F*). The features brought out in this photograph are: (1) each single apparent veinlet consists of a thread of quartz which disagrees in extinction position with the parent crystal; (2) the crystallographic orientation of the quartz in parallel threads, the traces of roughly parallel planes, is the same; (3) the orientation in one set of planes is not the same as in the other set.

Since the quartz in these planes is not parallel to that in the parent crystal, they cannot be a result of fracturing and later filling such as causes "phantom" veinlets. Judd[41] has shown that a lamellar twinning parallel to (r) and (z) may be developed in quartz by pressure. It is possible that the phenomenon pictured is related to this gliding described by Judd.

Typical microscopic brecciation needs no description, for its features are miniatures of those of large scale brecciation. The following "shredding" of quartz, which is somewhat analogous

[39] U. S. G. S. Bull. 580, p. 161.
[40] *Mineralogical Magazine*, Vol. VII., 1886, p. 82, 83.
[41] *Mineralogical Magazine*, Vol. VIII., 1888, p. 1.

to "slicing," and recrystallization by strain, are, however, phenomena which are worth separate mention.

Shredded Quartz.

A rather unusual effect of shearing is shown in Pl. XXVII., *A*. Large quartz crystals have been fractured into aggregates of roughly columnar fragments, which have distinct but not widely separated extinction positions. Extreme shearing produces a shredded or fibrous texture. Quartz which has this appearance under the microscope is usually platy in the hand specimen.

Quartz shredded by strain is easily confused with other rather rare phenomena which have the same appearance; *e.g.*, a similar structure has been observed: (1) in quartz pseudomorphic after shredded siderite; (2) in the rearrangement quartz shown in Pl. XXVIII., *D*; (3) in slightly fractured combs of slender quartz prisms; and (4) in the variety of replacement quartz shown in Pl. XXVI., *C*.

Recrystallization of Quartz.

The word "recrystallization" has been used to denote a number of varied, though associated phenomena. As a factor in the development of metamorphic rocks and rock cleavage the process has been thoroughly discussed by Leith[42] and Van Hise.[43] The various ways in which the term is used with respect to individual crystals may be summarized from the discussions by Van Hise, who describes three major processes of recrystallization. These are: (1) the solution of mineral material at points of greatest pressure, and the simultaneous deposition of mineral material at points of least pressure; (2) the coalescence of very small mineral particles to produce larger particles; (3) the breakdown of larger crystals to form an interlocking aggregate of smaller crystals.

Evidence of the first process has not been observed in vein

[42] U. S. G. S. Bull. 239, 1905.
[43] U. S. G. S. Mon. 47, 1904.
Bull. Geol. Soc. Am., Vol. I., 1890.
Bull. Geol. Soc. Am., Vol. IX., 1898.

quartz. Recrystallization by coalescence is mentioned later under the head of "rearrangement," As it was not observed as a pressure phenomenon, this process has not been included under this heading. The third phenomenon, recrystallization by the breakdown of large crystals to small ones, is usually the result of strain, and is often accompanied by distortion and granulation. This process in pegmatitic quartz has been pictured by Bastin.[44] The phenomenon is often a definite characteristic of certain deep-seated quartz veins.

Recrystallization of quartz by the breakdown of large crystals to an interlocking aggregate of smaller individuals is developed prominently in quartz ores from the gold fields of West Australia; from the Mother Lode of California; and from the Juneau gold belt in Alaska. Thin sections cut from unstrained specimens from these districts show that the vein material is an aggregate of coarsely granular subhedral quartz crystals. Before recrystallization all of the quartz contained inclusions of gas, minute mineral matter, and occasionally liquid with gas bubbles.

The first step in the process is a disturbance of the optical continuity of a crystal, producing strain shadows, of wavy or undulatory extinction. Incipient recrystallization closely follows initial strain. It appears as a more pronounced undulatory extinction in which small, rather definite, areas may be seen to extinguish at once, giving the crystal a rough and mottled appearance. Incipient recrystallization can only be detected by this mottling of high lights when the parent crystal is at the maximum extinction position, thus furnishing a dark background for contrast. At the position of maximum transmission for the main crystal, the variance in interference color is so slight as to be imperceptible. As recrystallization progresses the divergence in optical orientation between original and the recrystallized portions increases. Pl. XXVII., *B*, shows a single strained quartz crystal, with partial recrystallization. The final stage is an interlocking aggregate of rather equidimensional quartz. Van Hise[45]

[44] "Geology of the Pegmatites and Associated Rocks of Maine," U. S. G. S. Bull. 445, 1911, Plate VI.

[45] Bull. Geol. Soc. Am., Vol. I., 1890, p. 217.

has outlined the process in connection with quartz in metamorphic rocks: "An individual, instead of extinguishing upon the whole as a unit, is now composed of individuals which extinguish more or less independently, although the positions of extinction are not far from each other, except the grain has been wholly destroyed." When recrystallization is complete throughout a slide, the contacts of original crystals are obliterated.

The recrystallized quartz shown in Pl. XXVII., *B*, is entirely anhedral, with ragged borders. In some specimens, the quartz is subhedral, with straight outlines and occasional euhedral cross sections (Pl. XXVII., *C*). The speckled areas are remnants of the original crystal.

Recrystallization is apt to proceed along certain surfaces more often than by simultaneous development throughout the whole of a crystal. These surfaces may be irregular and without definite orientation. Usually they approximate planes. Lines of recrystallization may run continuously across a slide, or may be confined to individual crystals. In this case a common arrangement is two intersecting sets of lines which recall the grid pattern of inclusions. In some thin sections recrystallization occurs largely along the edges of minerals where they are in contact with others, giving the appearance of a "mortar" structure. The progress of recrystallization is the same in these cases as in that described above, starting with initial slight optical displacements which gradually increase. Usually recrystallization starting in lines spreads throughout the mass on increasing development.

An interesting example of complete recrystallization is found in a specimen of ribbon quartz from the Sons of Gwalia mine. The rock is a compact, brittle quartz with closely spaced sheeting planes surfaced by sericite and a little calcite. Under the microscope the quartz shows no crushing or fracturing, nor are the individual grains strained so as to present undulatory extinction (Pl. XXVII., *D*). As a rule, however, in longitudinal sections they are slightly elongated parallel to the sheeting planes. Also, they show evidence of crystallographic continuity in certain roughly lenticular areas. This ribbon quartz is produced by the

recrystallization of larger quartz individuals. A phenomenon similar to this ribboning—"stretched" pebbles—has been attributed by Phalen[46] to recrystallization under pressure.

Occasionally complete recrystallization is found along certain lines while the main crystal is unaffected. Pl. XXVII., *E* and *F*, picture a quartz crystal which is in complete recrystallization along a lattice of planes. The areas of recrystallization are enlarging to include the whole crystal. For each set of planes there is one position in which a majority of its individuals are in or near extinction. When the process passes from the incomplete to the completed stage of recrystallization no such single position will cause a majority of crystals to extinguish. This is because of the gradually increasing divergence of optical orientation.

One very consistent, though not invariable, phenomenon shown throughout the slides examined is the loss of inclusions by recrystallization. The new quartz, though containing occasional bubbles and mineral particles, is distinctly clear in comparison to the original crystals. Pl. XXVII., *C*, illustrates clear subhedral quartz which has recrystallized from a large strained, clouded crystal. The remnants of this original crystal, showing undulatory extinction, may be seen in the photograph. In many of the thin sections this loss of inclusions is so pronounced that old and new quartz may be differentiated easily in ordinary light. A clouded area in the slide will almost invariably show some strain effect under crossed nicols, whereas the clear areas have perfectly sharp extinction. This unstrained condition of the new quartz is to be expected from a process which is a rearrangement to relieve strain.

Pl. XXVII., *E*, shows the loss in inclusions by the grid structure recrystallization progressing in Pl. XXVII., *F*. This loss is an indication that the recrystallization phenomenon is not simply a granulation or a fracturing into a number of slightly dislocated portions. In fracturing there would be no reason for a loss of inclusions except along the break itself.

[46] *Jour. of Geol.*, Vol. XVIII., 1910, p. 554.

SUMMARY.

The type of recrystallization of quartz here described is a result of strain, and its location depends upon the localization of strain. The phenomenon is a molecular rearrangement throughout a crystal to relieve its strained condition.

Recrystallization of this type does not appear in prominence in quartz from those deposits which are known to have been formed near the surface. In contradistinction, it is often observed in specimens from such mining districts as the West Australia gold fields; Juneau, Alaska; Homestake, South Dakota; Porcupine, Ontario; and the California gold belt. Ores from these districts are generally considered to have been formed at considerable depth, and under great pressure. Strain recrystallization is, then, a phenomenon which might be expected in these deposits. Conversely, its occurrence in any quartz ore, in such prominence as to be considered a characteristic, may be taken as an indication that the quartz was formed at considerable depths.

REARRANGEMENTS OF SILICA.

Crystallization of quartz from the hydrogel condition and recrystallization of quartz under pressure (previously described), in their characteristic occurrence, represent opposite extremes; in origin, also, they are widely separated. Between these extremes there may be a continual rearrangement of silica. This may take two forms: (1) the coalescence of small crystals to produce large ones; (2) the reduction of large crystals into finer grained aggregates.

The alliance of rearrangement to replacement is obvious. Replacement, however, presupposes a change in chemical composition, whereas rearrangement concerns only the internal molecular structure. The two processes of rearrangement may be briefly illustrated.

Secondary enlargement of quartz by introduced silica has been pictured (Pl. XXIII., *E*). Secondary enlargement in which the silica is derived from neighboring crystals is shown in Pl.

XXVIII., *A*. The path of solution in a specimen may be marked by stains, while the actual duct is imperceptible. Rearrangement of quartz along a solution duct may be prominent in places, and in other places absent, so that the duct is indicated only by the line of stain. The veinlet of which Pl. XXVIII., *A*, is a part, is of this intermittent character. In the portions pictured, microcrystalline silica has coalesced to large crystals whose growth outward from the veinlet is apparent.

The second process is illustrated by Pl. XXVIII., *B*. Staining shows the path of solution traversing coarse quartz. Rearrangement of silica along the veinlet is complete in the crystal to the right and is incipient at each side of the central grain.

These two processes will often destroy the original structure of the vein material, when that structure is entirely dependent on variations in the size of its minerals, for rearrangement tends to produce an even grain.

Rearrangement which is gradually obliterating comb structure is shown in Pl. XXVIII., *C*. The line between the comb quartz and encrusted wall is ill-defined. Silicification of the country rock is accompanied by a rearrangement of silica at the base of the quartz prisms. Rearrangement in breccia has been pictured in Pl. XXV., *A*, in which quartz is the only transparent mineral present, the structure formerly being preserved by the variation in grain. The progressive change from fine to coarser grain is self-evident. Here, breccia structure is being destroyed by development of an even grain.

In some instances rearrangement emphasizes a structure. Development of a brecciated appearance by rearrangement of quartz is shown in Pl. XXVIII., *D*. In this case the rock originally was complexly fractured, but the separate fragments were not dislocated with respect to each other. Quartz cementing the minute fractures grew by the process of rearrangement into the wall rock, and normal to the fracture. The roughly prismatic crystals extend from one wall to the other and project irregularly into the fragments.

In other cases, inclusions retained by the rearranged quartz

preserve the former structural outlines. This is shown by Pl. XXVIII., *E* and *F*. With one nicol, a former drusy, cellular structure is outlined by the opaque material, but under crossed nicols the field becomes an aggregate of anhedral grains whose distribution is entirely unrelated to the original structure. In this case, replacement of other minerals of the drusy period, by quartz, preceded or accompanied rearrangement of the quartz itself.

SUMMARY OF PART II.

The ordinary replacement structures of quartz are not varied except when the structure is an inherited one. Replacement quartz is usually anhedral. Exceptions to this rule are most frequent in replacements of such easily soluble minerals as calcite, in which euhedral quartz crystals sometimes are prominent. Replacements by quartz, when widespread and complete enough to be called "silicification," usually consist of fine grained or microcrystalline quartz. Coarse replacement quartz is less common in the fissure veins under discussion. It must be remembered that this article deals only with quartz of hydrothermal origin. In the majority of such veins the quartz is the primary filling, so that there is little opportunity for later silicification of the vein material itself. Thus the deep-seated veins of the Mother Lode type show little evidence of replacements by quartz. However, in those deposits in which the vein material contains other minerals in prominence, or fragments of country rock, replacement may be important. In most breccias and sheeted zones encrustation and replacement are inseparable. The extent and causes of replacement in the country rocks of veins are not considered in this article.

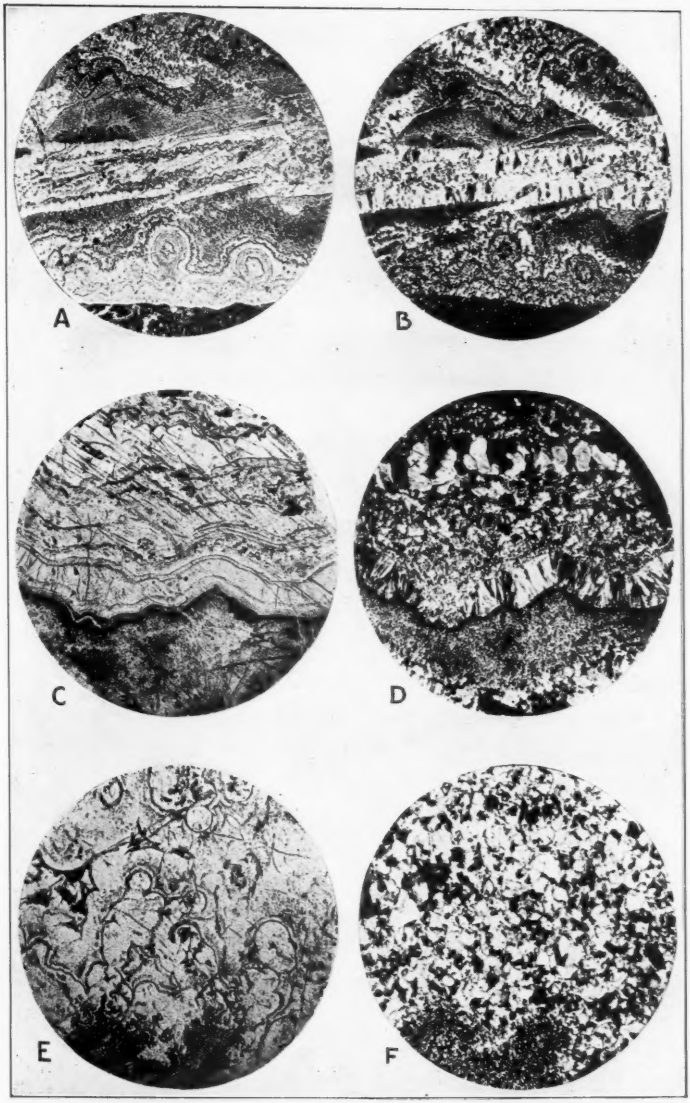
Effects of pressure, especially recrystallization by strain, are of importance in that they give a clue to the type of vein in which they occur. As a generalization, it may be said that the majority of veins now mined were at their greatest depth below the surface at the time of their formation. Deformation by strain, then probably occurred at depths not exceeding those at which the

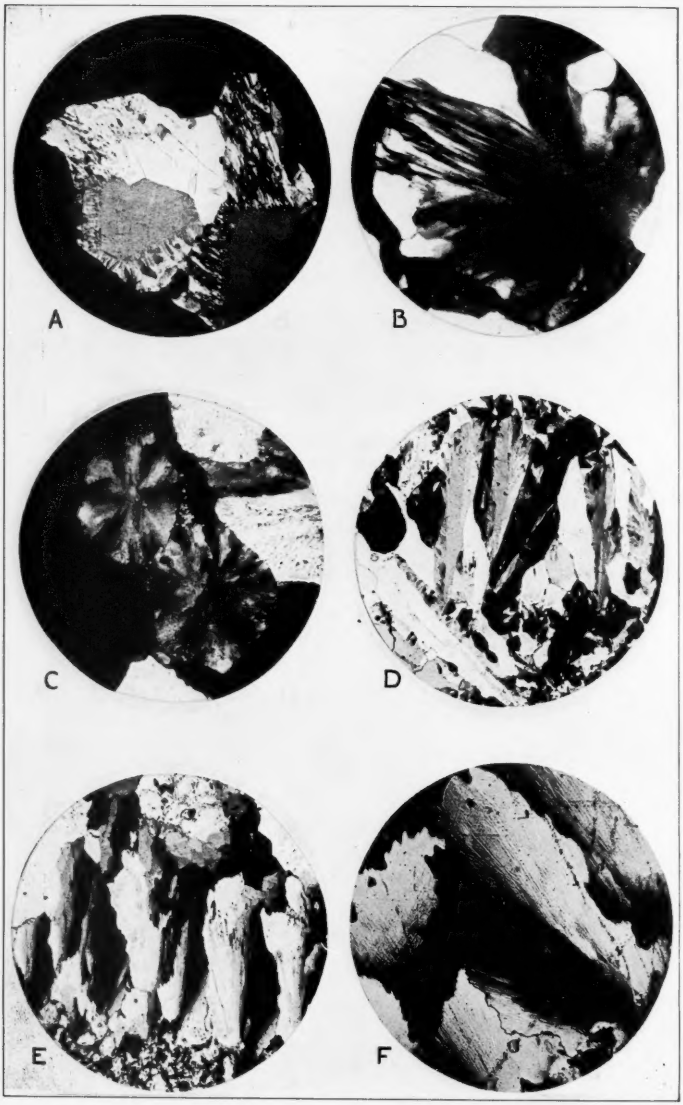
EXPLANATION OF PLATE XXI.

A (one nicol) and *B* (x-nicols). Colloform gel banding; microcrystalline quartz and chalcedony; zonal growth lines in comb quartz; parallelism of comb quartz individuals. Gold Road, Ariz. (×35.)

C (one nicol) and *D* (x-nicols). Fibrous chalcedony; crustification banding flamboyant quartz (at left of upper band, -marked '*x*'). White Rock, Australia. (×35.)

E (one nicol) and *F* (x-nicols). Micro-botryoildal gel structure, its preservation by inclusions in flamboyant quartz crystals; these crystals are unrelated to the structure of the original gel. Talisman Mine, New Zealand. (×35.)


A
B
C
D
E
F


A
B
C
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E
F

EXPLANATION OF PLATE XXII.

A (x-nicols). Feathered quartz with perfect core. Kingman, Ariz. (× 35.)

B (x-nicols). Feathered cross effect when anomaly has not a perfect core. (× 108.)

C (x-nicols). Ideal view of cross effect (upper crystals); typical appearance of anomaly (lower crystal). Rawhide, Nev. (× 108.)

D (x-nicols). Typical feathered quartz prisms. Caledonian Mine, Thames, New Zealand. (× 36.)

E (x-nicols). Flamboyant quartz encrusting vein wall. Talisman Mine, Karangahake, New Zealand. (× 37.)

F (x-nicols). Typical flamboyant quartz showing radial relief lines. Talisman Mine, Karangahake, New Zealand. (× 60.)

EXPLANATION OF PLATE XXIII.

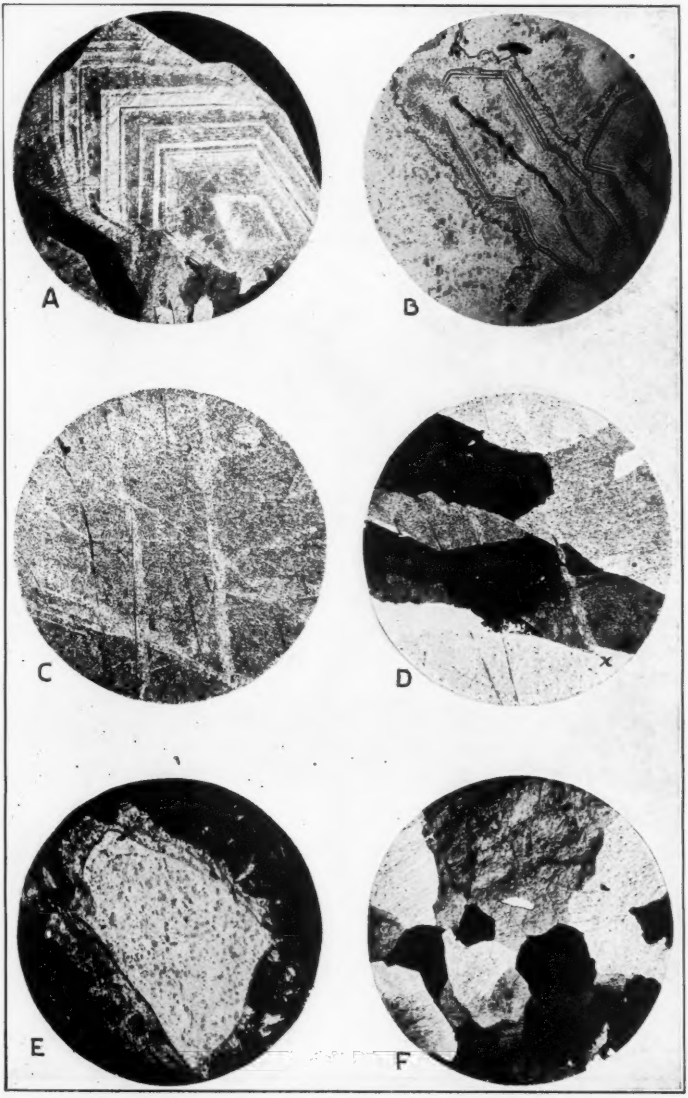
A (x-nicols). Zonal markings by inclusions. Union Mine, Austin, Nev. (× 36.)

B (one nicol). Zonal markings by lines of relief, probably microscopic bands of chalcedony in this figure. Salisbury Gold Mining Co., W. Australia (× 106.)

C (one nicol) and *D* (x-nicols). Phantom veinlets. Notice offset of crystal at *x*. Union Hill Mine, Grass Valley, Calif. (× 37.)

E (x-nicols). Secondary enlargement of fragment in tuff. Jarbidge, Nev. (× 77.)

F (x-nicols). Anhedral interlocking quartz. Alaska Treadwell Mine, Alaska. (× 33.)


A
B
C
D
x
E
F

A
B
C
D
E
F

EXPLANATION OF PLATE XXIV.

A (x-nicols). Interlocking coarse quartz. Early prism enclosed by later quartz crystal. Nevada City, Cal. (× 18.)

B (x-nicols). Crustification banding (megascopically fine grained). Pachucha, Mex. (× 35.)

C (x-nicols). Crustification; radial arrangement of comb quartz suggesting flamboyant structure. Talisman Mine, New Zealand. (× 18.)

D (x-nicols). Comb quartz with anomalous habit. Aspen Mine, Silvertown, Col. (× 19.)

E (x-nicols). Quartz in small cavities; zonal growth lines. Sandstorm claim, Goldfield, Nev. (× 49.)

F (x-nicols). Drusy quartz. Hormiguero, Mexico. (× 16.)

EXPLANATION OF PLATE XXV.

A (x-nicols). Microcrystalline replacement quartz in breccia. Goldfield, Nev. (× 36.)

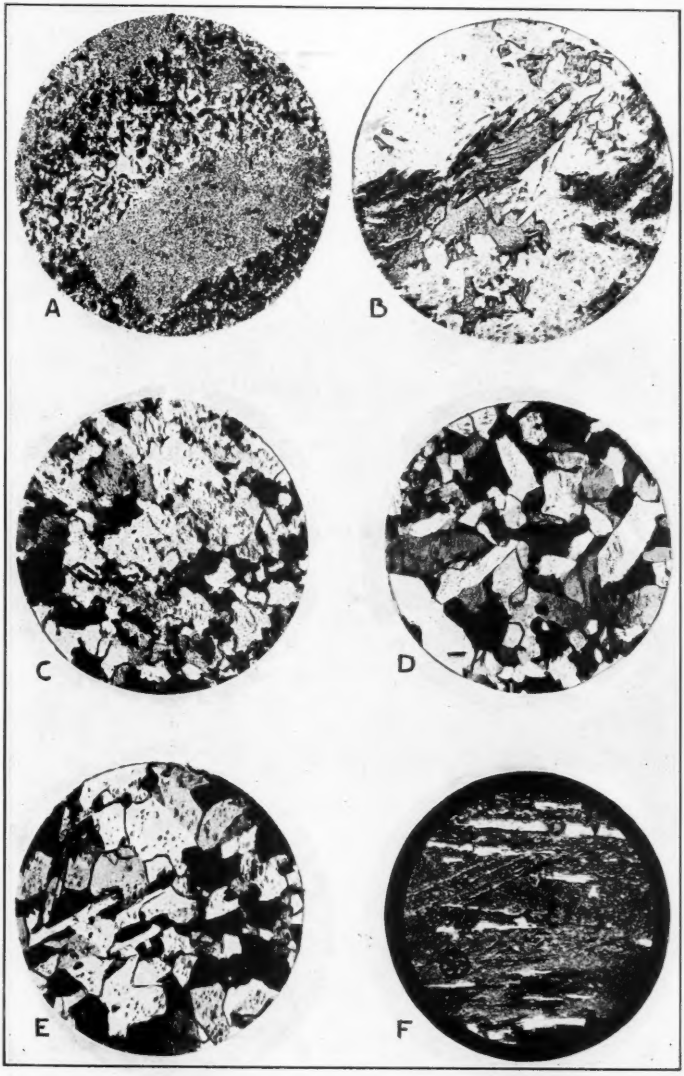
B (one nicol). Euhedral replacement quartz in calcite (quartz, white; calcite, grey). Ikuno-tasei Mine, Japan. (× 38.)

C (x-nicols). Anhedral replacement quartz. Republic, Washington. (× 100.)

D (x-nicols). Subhedral replacement quartz (completion of *B*). Ikuno-tasei Mine, Japan. (× 114.)

E (x-nicols). Inherited platy structure in replacement lamellar quartz. Gold Road, Ariz. (× 65.)

F (x-nicols). Replacement of lamellar calcite along basal parting. Gold Road, Ariz. (× 114.)


A
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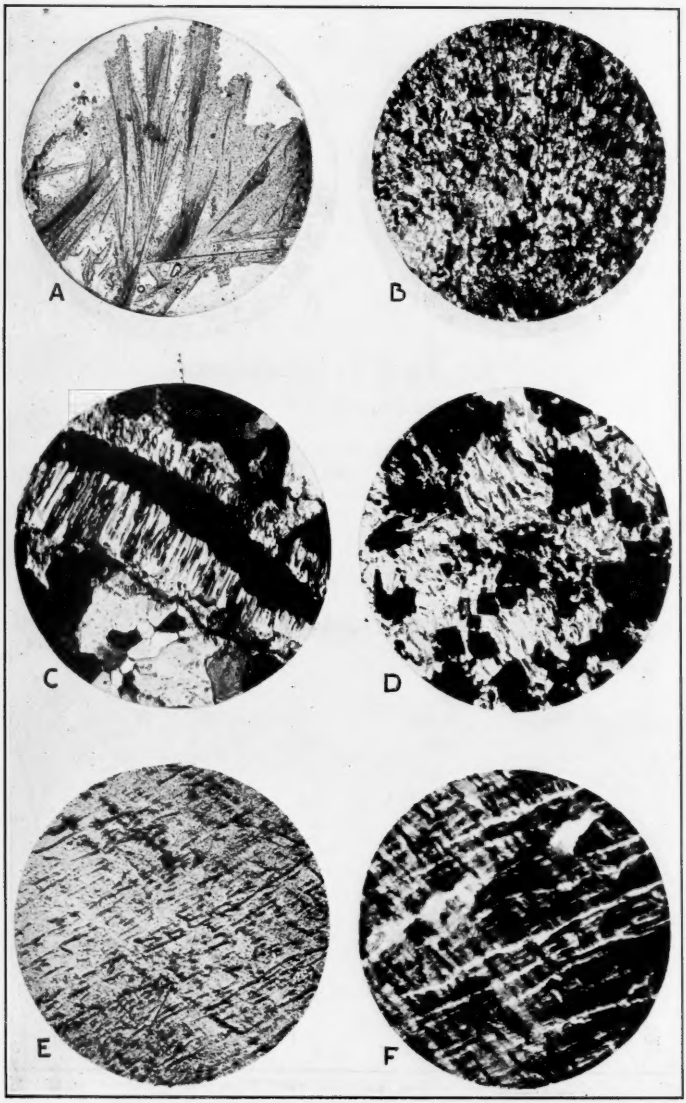
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EXPLANATION OF PLATE XXVI.

A (one nicol). Lamellar structure; quartz chalcedony, and adularia pseudomorph after replaced calcite. Jarbidge, Nev. (× 18.)

B (x-nicols). "Radial" quartz structure; probably pseudomorph after calcite. Republic, Washington. (×—.)

C (x-nicols). Anomalous replacement quartz normal to pyrite veinlet. Oak Run prospect, Shasta Co., Cal. (× 55.)

D (x-nicols). Anomalous replacement quartz in pyritized schist. (Thin section lent by C. F. Tolman, Jr.) Campo Seco, Cal. (× 36.)

E (one nicol) and *F* (x-nicols). Inclusional pattern by strain; twinning by gliding (?). Union Hill Mine, Grass Valley, Cal. (× 104.)

EXPLANATION OF PLATE XXVII.

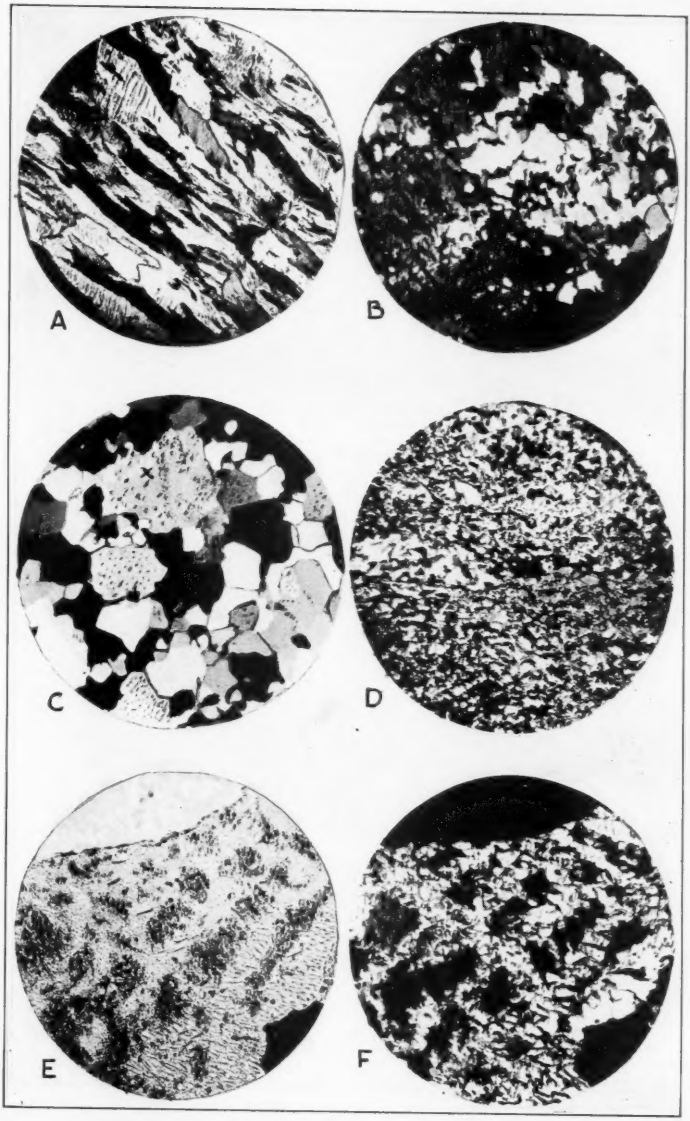
A (x-nicols). "Shredded" quartz by pressure. Cobar, Australia. (× 35.)

B (x-nicols). Recrystallization by stain of single quartz crystal. Sons of Gwalia Mine, W. Australia. (× 47.)

C (x-nicols). Subhedral recrystallization quartz; loss of inclusions by strain. (Largest Remnant is *x*.) Boulder Deep Levels, W. Australia. (× 66.)

D (x-nicols). Complete recrystallization in ribbon quartz. Sons of Gwalia Mine, W. Australia. (× 39.)

E (one nicol) and *F* (x-nicols). Recrystallization in grid pattern; loss of inclusions. Kennedy Mine, Jackson, Cal. (× 142.)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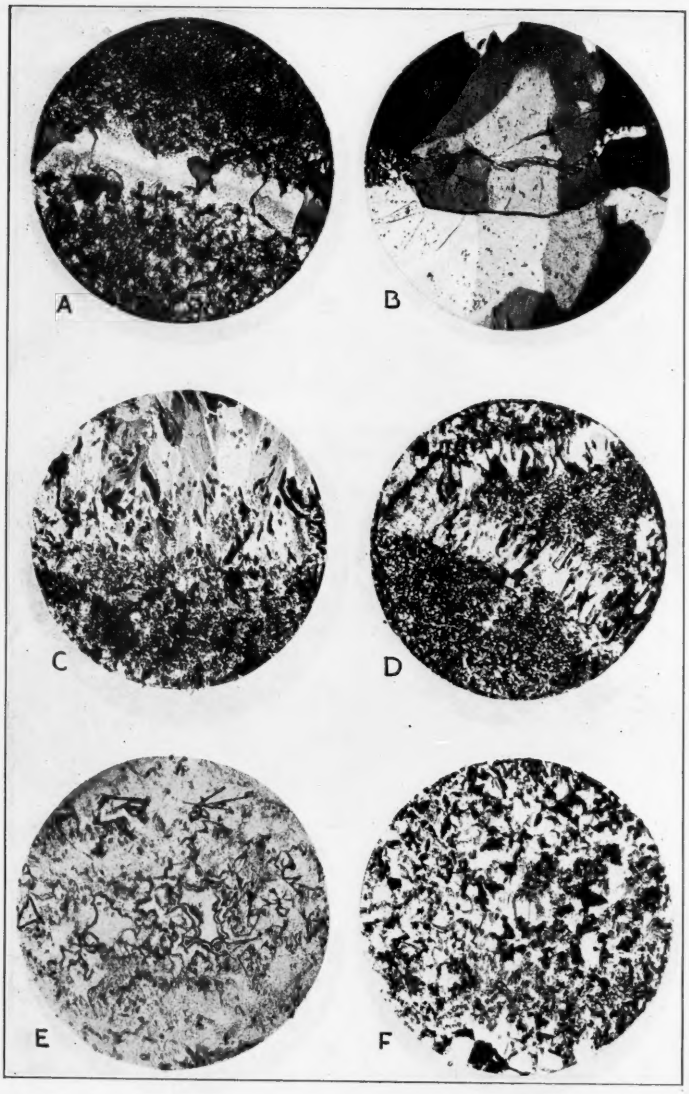
A
B
C
D
E
F

EXPLANATION OF PLATE XXVIII.

A (x-nicols). Rearrangement by coalesence. White Rock, Australia. (× 114.)

B (x-nicols). Rearrangement by break down of large crystals to small ones. White Rock Australia. (× 114.)

C (x-nicols). Rearrangement of quartz destroying comb structure. Caledonian Mine, Thames, New Zealand. (× 36.)

D (x-nicols) . Rearrangement quartz veinlets; individuals growing into silicified wall rock. Cobar, Australia. (× 55.)

E (one nicol) and *F* (x-nicols). Rearrangement; drusy structure retained by inclusions in quartz entirely unrelated to structure. White Rock, Australia. (× 35.)

vein material was deposited. If so, the type of strain indicates the character of the vein: *i.e.*, whether deep-seated or superficial. Brecciation results from unequal pressure, or stress, and though most widespread where there is little load (*i.e.*, near the surface) may be found at any depth at which fissures may exist. Such strain phenomena as the distortion of a crystal without rupture, and recrystallization, however, can only have taken place under the conditions of immense but rather uniform pressure of deep-seated deposits. It has been shown that their occurrence is limited to these vein types.

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CALIFORNIA.

HIGH-GRADE TALC FOR GAS BURNERS.

J. S. Diller,[1] J. G. Fairchild, and E. S. Larsen.

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INTRODUCTION.

Talc in its natural condition is a useful mineral. It is soft, sectile, and flexible, but not elastic, and has a decided slippery feel. When homogeneous and compact it may be readily cut to any desired shape and adorned with fine carvings. Being fusible only with difficulty on thin edges, and not affected by ordinary acids, it is stable and indestructible under a wide range of physical and chemical conditions.

Talc contains a small percentage of water which is given off only at red heat. Impurities, especially oxide of iron and silica or grit, depreciate its value. In general the purer the composition and the finer and more homogeneous the structure the higher the grade of talc. When crystalline it is foliated, but

[1] Mr. Fairchild made the chemical analyses and Mr. Larsen did the microscopical work. Paper published by permission of the Director of the U. S. Geological Survey.

aggregates of it may vary in structure from very fine, uniformly compact to distinctly granular.

Talc may be applied in the industries either ground, as "talc flour," or unground, as crude talc. Ground talc is most extensively used as a filler in making paper. It is largely employed also in the manufacture of toilet powder, as a filler for paints and lubricants, and for foundry facing, besides many other uses of less importance.

In its crude form talc is most widely employed in the manufacture of pencils or crayons for use on slate or metal, or as French chalk for marking on cloth. In later years it has been used for electric insulators and gas burners, but for these purposes, especially the latter, the United States is deficient in the supply of good material. The object of this paper is to call attention to this lack of supply and to point out certain conditions that have influenced the origin of suitable material, in the hope that domestic production may be increased.

HISTORY.

Although talc was quarried at Göpfersgrün in the Fichtelgebirge and used in Germany as early as 1724 its first application in the manufacture of gas tips in that country was not made until a much later date. Subsequently the work was taken up in the United States, at Cincinnati, by D. M. Steward who used domestic talc first and then that from Germany and India. Some years ago the D. M. Steward Company established its manufactory at Chattanooga, Tenn., and that city has since become an important gas-tip center, as three other manufactories are now operating there. Several other manufactories are located in New York.

PRODUCTION AND IMPORTS.

The production in the United States of talc suitable for gas tips has been limited to North Carolina, Georgia, and Maryland. Much of the material used in 1901 was quarried at Hewitts, N. C. Other localities farther southwest in North Carolina and Georgia were discovered and developed later, and a locality in

Maryland was opened within the last few years. The total output of the grades required for gas burners in recent years has been very small—far from sufficient to supply even the demand of a small industry which in times of peace has depended for its stock of raw material upon imports from Italy, France, Germany, and India. The total amount used annually in the United States for this purpose probably does not exceed 1,000 tons.

The principal sources of imported high-grade talc are Italy and France, which rank first and second respectively in both quantity and quality. Imports from Italy during the last 8 years averaged 4,300 tons valued at $27 a ton, and those from France in the period averaged 2,850 tons valued at $12.50. It is not known how much of these imports from either country is suitable for gas burners.

MODES OF OCCURRENCE.

The most common mode of occurrence of talc used for gas burners, is in metamorphic limestone, but some talc used for this purpose has been found in altered basic igneous rocks.

DOMESTIC DEPOSITS.

Only two domestic deposits have furnished talc for gas burners on a commercial scale. These are at Hewitts, Swain County, N. C., and in Harford County, Md. Other deposits from which samples of high-grade talc have been obtained are found southwest of Hewitts, N. C., especially in the neighborhood of Chatsworth, Ga. The talc in these deposits may be foliated, fibrous, or massive, but only the massive variety can be used for gas tips.

Hewitts, N. C.—Little talc has been produced at Hewitts in recent years. The deposits, owned by the North Carolina Company, occur in large lenses which range up to 50 feet in thickness and 200 feet in length. These lenses which conform to the bedding of the limestone, stand nearly on edge along the steep slope of the valley and dip steeply to the southeast toward the river. They strike northeastward parallel to the river. Above the river level the lenses of talc have been exhausted, and under the river

the influx of water stopped mining some years ago. A chemical analysis of the talc (No. 5) on page 671 indicates its good quality.

The limestone beds are in part dolomite, and in part calcite. The rocks of the entire region, according to Keith,[2] who described the occurrences, have been greatly folded and compressed and most of the original sedimentary material has been recrystallized. The magnesium and hydrous silicates, including talc, are believed to have been derived by regional metamorphism from impure dolomite beds.

Dublin (near), Harford County, Md.—A deposit of talc that is being used for making gas tips was discovered a few years ago near Dublin, Harford County, Md., and is being worked by the Harford Talc Company. It is an altered portion of a large dike of basic igneous rock (pyroxenite?) which extends northeast and southwest across Susquehanna River at Conowingo, and forms a conspicuous geological feature in the northeastern part of the State. The dike is largely serpentine but generally contains much talc. In places the talc is so compact and of such high grade that it may be used for making gas tips. During the world war when imports were stopped it was the chief source of supply for that purpose, but was inferior to the imported talc. It is quarried in open pits extending northeast and southwest parallel to the more or less pronounced fissures of the rock and the water course which it follows. The pits are about 30 feet deep, and show the talc deposits to have an irregular width, which varies from 4 to 10 feet. The supply of material depends on the extent and completeness of the rock alteration. The deposit appears encouraging, and the quarry is being not only deepened but extended to the southwest. Much of the rock is massive and is quarried in large blocks which are sawed into blanks of various shapes and sizes. These blanks have fairly smooth surfaces and sharp edges.

The material is carefully selected and only the softest, most compact, and uniform is used. It has an uneven, short, splintery fracture with minute crystalline structure showing bright cleav-

[2] Keith, Arthur, U. S. Geol. Survey Atlas, Nantahala Folio (No. 143), p. 8.

age faces of foliated grains and a few black magnetic specks (magnetite), but not sufficient for the determination of ferric iron in the chemical analysis shown in column No. 6 on page 671.

FOREIGN DEPOSITS.

Germany.—The highest grade of talc yet found for gas tips occurs in altered limestone along a granite contact, near Wunsiedel, in Fichtelgebirge of Baden, Germany. This very exceptional mode of occurrence is illustrated and described by Gümbel,[3] and the genesis of the talc, which is pseudomorphous after quartz and dolomite, is described in detail by Weinschenk.[4] The pseudomorphic origin of the talc after quartz appears to have determined the very finely crystalline, high-grade character of this talc.

Italy.—Much of the talc of Italy is foliated crystalline and remarkable for its freedom from grit and other impurities, so that it is especially adapted for the manufacture of toilet powder. Massive portions only are suitable for gas tips. The talc of Italy occurs chiefly in the crystalline rocks intruded by siliceous diorites in Chisone Valley, near Perosa and Pinerolo, about 25 miles southwest of Turin. Talc schists are present in the same region but no mention is made of limestones on the geological map of the country and the origin of the talc deposits is not evident.

France.—The Department of Ariegne, near the north foot of the Pyrenees, furnishes more than four fifths of the total output of talc in France. The "French chalk," so widely known, comes from southeastern France, near Toulon, a port on the Mediterranean.

India.—India is an important producer of high-grade talc which is inferior only to that from Germany for the manufacture of gas tips.[5] The talc which is imported into this country from India comes through other countries so that its source does not

[3] Gümbel, C. W., "Geognostische Beschreibung des Königreichs Bayern III.," Fichtelgebirge, 1879.

[4] Weinschenk, E., *Zeitschrift für Mineralogie,* XIV., p. 305, 1888.

[5] Mallet, F. R., "Records of Geological Survey of India," Vol. XXII., Pt. 2, pp. 59–67, 1889.

appear in the list of imports. Wadia[6] describes the Indian talc as follows:

> It is of wide occurrence, forming large masses in the Archaean and Dharwar rocks of the Peninsula and Burma; workable deposits occur in Behar, Jabalpur, Salem, Idar, and Jaipur (Rajputana) and Minbu (in Burma). At most of these places it is quarried in small quantities for commercial purposes. In its geological relations this talc is often associated with dolomite (as in Jabalpur) and other magnesian rocks, and it is probable that it is derived from these rocks by metamorphic processes resulting in the conversion of the magnesium carbonate into the hydrated silicate. In other cases it is the final product of the alteration of ultra-basic and basic eruptive rocks. At Jabalpur and other places it is carved into bowls, plates, and vases; it is also used in making pencils for writing on wood or cloth and as a refractory substance in making jets for gas burners. The substance has also of late come into use as a paint of high quality for protecting steel.

CHEMICAL COMPOSITION OF TALC USED FOR GAS TIPS.

In order to compare the talc of Harford County, Md., with imported talc used for gas tips the following chemical analyses have been made by J. G. Fairchild in the chemical laboratory of the U. S. Geological Survey. The cut material[7] (blanks) for these analyses has been kindly furnished by Mr. P. J. Kruesi, president of the American Lava Co. of Chattanooga, Tenn., and the analyses are arranged from 1 to 6, according to Mr. Kruesi's opinion of the order of quality for gas burners, beginning with the best material.

MICROSCOPIC EXAMINATION.

A microscopic examination of the talc from Maryland (analysis No. 6) showed that it is made up mostly of talc in matted plates and fibers with a rather irregular texture. Few of the plates are over 0.3 millimeters in longest dimension and the average length is about 0.1 millimeter. In addition to the talc there is about 15 per cent. of chlorite which is rather irregularly dis-

[6] Wadia, D. N., "Geology of India," p. 326. 1919.

[7] The exact localities from which the samples came in the various countries are not definitely known.

TABLE I.

CHEMICAL ANALYSES OF TALC USED FOR GAS BURNERS.

	No. 1, German.	No. 2, Indian.	No. 3, Italian.	No. 4, French.	No. 5, North Carolina.	No. 6, Maryland.	No. 7, Theoretical for $H_2Mg_3Si_4O_{12}$.
SiO_2	61.37	61.00	61.52	61.44	61.35	58.68	63.5
Al_2O_3.....	1.96	2.12	0.84	1.52	4.42	3.75	
Fe_2O_3	None	None	None	None		Indeterminate[8]	
FeO	1.47	1,74	1,27	0.97	1.68	5.52	
MgO.....	30.23	29.83	31.38	31.55	26.03	26.80	31.7
CaO	None	None	None	None	0.82	None	
(Na_2O).....					0.62		
H_2O-, H_2O+.	5.36	5.56	5.42	5.19	5.10	5.33	4.8
	100.40	100.25	100.43	100.67	100.02	100.08	100.0

[8] Chemical analysis gives negative result for Fe_2O_3.

tributed through the mass. This chlorite is of two varieties with alternating lamellae. The more abundant is very faintly birefracting, has an index of refraction of 1.61, and has negative elongation; it is pleochroic with α and β green and γ straw yellow. The other has a somewhat higher index of refraction and birefringence, has positive elongation, and is pleochroic β and α green, α straw yellow. These properties indicate that the more abundant chlorite with negative elongation is aphrosiderite and the other is delessite. A very little magnesite is also present. Assuming that the chlorite is between aphrosiderite and delessite and calculating all the Al_2O_3 into the chlorite, the mineral com-

TABLE II.

PROBABLE MINERAL COMPOSITION OF TALC SAMPLES AS CALCULATED FROM THEIR CHEMICAL ANALYSES.

	Germany, 1.	India, 2.	Italy, 3.	France, 4.	Maryland, 5.
Aphrosiderite	7.7	8.3	3.2	5.2	15.4
Talc	91.5	90.1	98.8	95.8	83.4
Excess SiO_2.....	1.0	1.6	—	—	1.7
Deficient SiO_2.....	—	—	1.9	1.3	—

position calculated from the chemical analysis is given in Table II., column 5.

The talc from Germany (analysis No. 1) is made up of ex-

ceedingly fine, irregularly interlocking plates and fibers rarely 0.05 millimeters in length and averaging much smaller. No chlorite was recognized but with such finely crystalline material it would be difficult to distinguish between colorless chlorite and basal plates of talc. The mineral composition as computed from the chemical analysis is shown in Table II., column 1.

The talc from India, represented by sample 2, is fine textured and few of the grains reach 0.1 millimeter in length while the average is about 0.05 millimeter. The talc plates and fibers are irregularly matted together. Little nearly colorless chlorite was found and only a little magnetite. The composition calculated from the chemical analysis is given in Table II., column 2.

The talc from Italy (analysis No. 3) carries a little chlorite (estimated 5 per cent. and more than the analysis indicates) similar to that in the Maryland talc, but paler in color. It is in aggregates of minute crystals up to 3 millimeters across that look like replaced crystals. The talc is in matted plates and fibers, partly aggregated in bundles, and rarely over 0.2 millimeter long and averaging about 0.05 millimeter. There are a very few grains of magnetite. Irregular seams across the specimen are rudely parallel. The mineral composition as calculated from the chemical analysis is shown in column 3, Table II.

The talc from France (analysis No. 4) is in matted plates with a strong tendency to parallel arrangement giving the specimen a platy or schistose structure. The talc plates are up to 0.1 millimeter in length and average much less. A little chlorite is present in aggregates like the chlorite of the Italian talc, and a little magnetite. A single grain of carbonate 1 millimeter across is present in the section, and a minute garnet (?) is also present. The mineral composition as shown from the chemical analysis is shown in Table II, column 4.

CONCLUSION.

The most essential properties of the best talc known for gas tips are dependent on composition and texture. Even the highest grade of material used for that purpose appears to be not pure

talc but a mixture of talc and chlorite. All the analyses contain alumina, and when the material is not too finely crystalline the microscope always shows the presence of chlorite varying from 3 to 15 per cent. When the proportion of chlorite is large the material becomes too rich in water and commonly in ferrous iron, both of which are deleterious constituents as when the cut material is baked the loss of water causes it to contract and fracture and the liberation of iron oxide, probably from the chlorite, makes the talc more porous and of a less attractive, darker brown color.

Next to composition, fineness and uniformity of texture is the most essential property of grade. In this respect the German talc excels all others. Its constituent particles are so minute that it appears to be practically without grain. It cuts almost like cheese to a sharp edge and a smooth bright surface with scarcely perceptible microscopic grain. Most of the talcs used are clearly granular and the grade is determined largely by the fineness and uniformity of the grain.

As regards origin, the German talc according to Gümbel and Weinschenk (page 669), differs from the others in being a product of contact metamorphism, in which chemical action alone was dominant, rather than of regional metamorphism, in which mechanical deformation as well as chemical action was an important factor. Its pseudomorphic origin after quartz and dolomite, to which its extremely fine grain is attributed, is also a distinctive feature. In view of these unusual characteristics, the contact-metamorphic zones between limestone and granite appear to be favorable places for prospecting in the United States. Talc is not prominent, however, in any of the well known metalliferous contact metamorphic deposits in the Cordillera where the intrusive rocks are monzonites, diorites, and granodiorites, and the word granite in the foregoing sentence should be applied in the restricted petrographic sense.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

DISCUSSION.

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

GEOLOGISTS AS WITNESSES IN MINING LITIGATION.[1]

Sir: The discussion of the participation of geologists in mining litigation appearing in the pages of this and other technical magazines in recent months has been followed with much interest by those of us who have occasionally had to consider this problem in relation to our own professional work. I have been especially interested in contributions of Professor Kemp and Dr. Ransome and am glad to accept your invitation to continue this discussion.

In the United States there is a wide use of geologists as witnesses in litigation affecting "extralateral rights." The federal mining law gives the owner of the claim containing the "apex" or top of a mineral vein or lode the right to follow the vein down the dip, with certain limitations, even though this takes him onto adjacent properties under other ownership. Where two branches of a vein are followed down from separate claims, the owner of the oldest claim is entitled to the vein below the point of junction. The law was framed to validate a procedure more or less established by mining custom. It was obviously framed with a very simple and definite conception in mind—namely, a simple vein definitely and easily followed, without much interruption or contortion.

[1] This is substantially an excerpt from the writer's "Economic Aspects of Geology," now in press.

In nature, however, veins or lodes have a most astonishing variety of form and occurrence, making it difficult to frame a definition that is comprehensive and at the same time sufficiently precise for all cases. A commonly used definition of a vein or lode is a mineralized mass of rock which is followed for purposes of finding ore. The mineral matter may be continuous or discontinuous. There may be one definite wall, or two walls, or none at all. There may be associated gouges and altered or mineralized rock. The vein may consist of almost any combination of the elements of mineral matter, walls, gouges, and mineralized rock. Instead of being a simple tabular sheet, a vein may have almost any conceivable shape; it may consist of multiple strands of most complex relations; it may have branches and cross-over connections. It may be a more or less mineralized sedimentary formation with limits determined by original deposition. It is very often bent or folded, and even more often faulted; the faulting may be of great complexity, making it extremely difficult to follow the vein. The vein may be cut by other veins of different ages, which in places may be hard to distinguish one from another. Erosion working down on a complex vein displaced by faulting and folding may bring several parts of the same vein to the surface, developing what seemed to be separate vein apices. Where there are many veins close together, it may be difficult to determine whether the entire mass should be considered a unit vein or lode (a "broad lode"), or whether each vein should be considered independently under the law.

The geologic aspects of these problems are obvious. There are few mining districts where the vein conditions are so simple that no geological problems are left to be solved with relation to extralateral rights. In the early stages of the mining, separate operations may be carried on for a considerable time in a district without mutual interference; but as mining is carried down the dip, what seemed to be separate veins may be found to be parts of the same vein or parts of a complex vein system, and separate mining organizations are thus brought into conflict. It then becomes necessary either to consolidate the ownerships or to go to

the courts to see which claim has the extralateral rights. In either case, the geologist is called on to play a large part—in the valuation of rights for the purpose of combination, or in litigation to settle apex rights. A geologic survey of the conditions is a prerequisite. In order to get the necessary information for the courtroom, it may be necessary to go further, and to conduct extensive underground exploration under geologic direction. Some of the most intensive and complete geological surveys of mineral resources in existence have been done for litigation purposes. The study in these cases is not empirical, but goes into every conceivable scientific aspect of the situation which may throw any light on the underground conditions—the source of the ores, the nature and source of the solutions which deposit them, their paths of travel, the structural and metamorphic conditions, the mineralogical and chemical character of the ores and rocks, and even broader questions of geologic age. The many volumes of testimony which have accumulated during famous apex trials cover almost every phase of geology, and are important primary sources for the student of economic geology.

It is often argued that strictly scientific, impartial geologic work is impossible in connection with one of these trials, because the viewpoint is warped by the desire to win. The sharp contrast in the views of experts on the two sides is cited in evidence.

There is no denying the fact that the conditions of a trial tend toward a certain warp in scientific perspective. On the other hand, the very existence of competitive and opposing interests leads to the most intensive detailed study and to complete disclosure of the facts. In most cases there are no substantial differences in the statements of scientific fact by reputable experts on the two sides, although there may be wide differences in the inference drawn from these facts. The failure to note a fact, or any distortion or misstatement of a fact, is followed so quickly by correction or criticism from the other side, that the professional witness usually takes the utmost pains to make his statement of fact scientific and precise as far as his ability goes. Few scientific treatises in geology contain any more accurate accounts

of mineral deposits than testimony in cases of this sort. If every student of geology, early in his career, could have a day on the witness stand on a geologic problem, under both direct and cross-examination, he would learn once and for all the necessity for close and accurate thinking, the difference between a fact and an inference, and the difference between inductive study of facts and the subjective approach to a problem.

It is a common assumption that a witness called to testify on scientific matters is on a somewhat different basis than the eye witness to an event or transaction. I am not sure that this assumption is justified. Seldom is it possible in mining operations to disclose the facts in three dimensions so completely that they may be empirically observed and platted by the layman. The grouping and presentation of the facts in adequate perspective includes an analysis of the origin of the ores and rocks, the rock alterations, the structural systems, and other facts. No one ever saw the vein or lode in the process of formation. The true nature of the event and of its physical results must be inferred inductively from circumstantial evidence. If it is conceded that it is necessary and right to call an eye witness to the event involved in litigation, it is equally necessary where there are no eye witnesses to call the people best qualified to interpret the circumstantial evidence.

It is to be remembered that apex cases are only one kind of a vast variety of cases affecting mineral resources. At one time or another, and in some connection or another, practically all geologists of considerable experience have found it necessary to testify on geologic matters in court. The wide interest attaching to certain spectacular apex cases has led in some quarters to hasty criticism of the participation of geologists therein, without apparent recognition of the fact that the criticism applies in principle to many other kinds of litigation and to practically all economic geologists. This criticism also fails to take cognizance of the fact that, for every case tried, there are many settled out of court through the advice and coöperation of geologists. While there may be in the geologic profession, as in others, a very

few men whose testimony can be bought outright, in general it must be assumed that geologists will appear on the witness stand only when, after careful examination, they are satisfied that there is a legitimate point of view to be presented.

Geologists and engineers understand more clearly than almost any other group the extent to which the complexities of nature vary from the conditions indicated in the simple wording of the law of extralateral rights. Almost to a man, they favor either modification or repeal of the law. On the other hand, the law has been in force since 1872, it has been repeatedly interpreted and confirmed by the courts, and a vast body of property rights has been established under it. Lawyers see great legal difficulties in the way of its repeal, or serious modification. Mining men for the most part are not primarily interested one way or another, unless there is potential application of the extralateral rights provision to their particular properties. Of those who are thus interested, some hope to gain and some fear they may lose in the application of the law. The general public naturally has little direct interest in the problem. There is thus no effective public sentiment favoring the repeal or modification of the law. It seems likely that for some time to come the law, in spite of its recognized defects, must be applied and the best geological effort must be directed toward reaching interpretations which come most nearly meeting its intent. To refuse to lend geologic science to the aid of justice because the law was improperly framed is hardly a defensible position. Presumably it will never be possible to frame laws with such full knowledge of nature's facts as to eliminate the necessity for scientific advice in their interpretation.

It has been suggested that the courts, and not the litigants, should employ the geologists. The practical objection to this proposition lies in the difficulty encountered by the judge in the proper selection of geologists. On the assumption that the judge would select only men in whom he had confidence, it is not likely that he would override their conclusions. The outcome of the case, therefore, would be largely predetermined at the moment

the selection of experts was made. It is to be doubted whether courts can have the knowledge of the scientific field and of the requirements of the situation necessary to make the wisest selection of men to interpret the given condition. The competitive element would be eliminated. From a judicial standpoint, there seems to be an equally good chance of getting at the best interpretation of the facts by listening to presentations from different standpoints, with the accompanying interplay of criticism and questioning.

Another practical objection to appointment of experts by the court is the limitation of court costs, which would make it impossible to secure the highest grade men. So far as these men are public employees, such as members of the federal or state geological surveys, this might be arranged. For others, it might be suggested that they should be willing to sacrifice their energy and time in the interest of justice; but as long as human nature and conditions are what they are, it is perhaps futile to argue this question.

If it is right to apply science to practical affairs, in other words, if the profession of economic geology is a legitimate one, it seems inevitable that the application must be in some part directed by the geologist himself, to avoid mistakes and confusion. The contention that the scientist must isolate himself in a rarified atmosphere to avoid contamination from a non-scientific, commercial, or legal atmosphere, seems to the writer practically untenable, if we recognize any obligation on the part of science to the practical conduct of human affairs. The fact that the geologist in making these applications may occasionally find himself in non-scientific atmosphere may be deplored from the standpoint of maximum creativeness in science and from this standpoint there may be reason for limitation of time given to this kind of work, but to stay out entirely on this ground is to deny his obligation to make his science helpful to his fellows. The problem cannot be solved by staying out. It rather calls for an especial effort on the part of the scientist to establish and maintain his standards of science and ethics in the applied fields. Some

doubtless fail in this effort. Others are strengthened scientifically and ethically, and contribute important aid in raising general standards. The principle of non-participation in such activities for fear of lowering scientific standards may make the geologist's problem easier, but at the expense of non-fulfillment of duties. Such a course has for its logical consequence an abandonment of the application of his science to untrained men without the ethical anchorage of scientific achievement. In short, there may be legitimate criticism of individual geologists for their methods and ethics in the applied field, and this is desirable as an aid to maintaining and improving standards, but it is not a logical step from this to the conclusion that to avoid unfortunate incidents, economic geologists must cloister themselves and thus deny the very implication of their title.

C. K. LEITH.

MADISON, WISCONSIN.

EXPERIMENTAL STUDIES OF SUBSURFACE RELATIONS IN OIL AND GAS FIELDS.

Sir: In a recent issue of ECONOMIC GEOLOGY[1] Mr. R. Van A. Mills has presented an elaborate discussion of numerous experiments on the relations of oil, gas and water in sand bodies. This work is highly essential and necessary for a more definite understanding of underground relations in oil fields of this country and elsewhere. Such studies should be of vital interest to petroleum geologists and the profession will doubtless gain considerable benefit from this and other papers which most likely will be written upon the subject.

This paper has been of especial interest to the author, since Mr. Mills has adopted the author's method of a glass-sided box, to show the relations of oil and water in sand and shale strata. While it is impossible to illustrate widespread field conditions or make allowances for great periods of time with such an apparatus in the laboratory, the enclosed box method, when the proper size of sand grains are used, will furnish a fair comparison for field

[1] ECONOMIC GEOLOGY, page 398, July–August, 1920.

conditions. The article is well written and the photographs are exceptionally good.

Mr. Mills has apparently missed a vital point in all previous discussion on the relation of oil and water in sand bodies. For all of his experiments have been made in a reservoir sand composed of grains ranging in diameter from 0.5 to over 6 millimeters. Sands "*a*" (diameter grain 6.35 to 1.651 mm.), "*b*" (diameter grain 0.833 to 0.589 mm.), "*d*" (diameter grain 1.168 to 0.833 mm.) and "*f*" (diameter grain 6.350 to 0.833 mm.) complete the list of his reservoir rock. Sands "*c*" (diameter grain 0.417 to 0.074), "*e*" (diameter grain 0.589 to 0.074) and "*k*" (diameter grain 0.295 to 0.074) were used only as cap rocks or impervious layers. Oil bearing sands show a general average of less than 0.3 mm. in diameter. This statement is also corroborated by the work of A. F. Melcher[2] where he shows the analyses of eleven oil-bearing sands with only two of the number which have a greater proportion than 10 per cent. over a 0.295 mm. diameter. In the summary, page 418, Mr. Mills[3] recognizes the fact that there may be a limit to the fineness of the spaces and consequently a lower limit to the size of the sand grains, where gravitational sorting will take place. He has neither shown the results of experiments with such a fine sand nor attempted in any way to analyze the condition. It is obvious that this condition is the most important one in the relation of oil and water underground, and Mr. Mills' experiments illustrate only a very special case which is not the average condition, judging from the samples of oil bearing sands analyzed to date.

Moreover the previous literature which Mr. Mills emphatically criticizes has never denied gravitational sorting in the size of openings used by Mr. Mills, but it in one place definitely stated:[4]

> The movement of oil in water-soaked sediments is almost entirely a problem of the surface tension. Water, having a greater surface tension

[2] "Determination of Pore Space of Oil and Gas Sands," *A. I. M. E.*, April, 1920.

[3] *Op. cit.*, page 418.

[4] McCoy, "Notes on Principles of Oil Accumulation," *Jour. of Geol.*, XXVII., pages 257–58.

and attraction for rock surfaces than oil, moves into the smaller pores occupied by the oil and forces it into larger openings. Such movement is characteristic as long as the openings are less than 0.1 mm. Where the sand grains are unusually large (3 mm. in diameter or over) or where induced openings have been made locally in some hard formation, sorting due to specific gravity is free to take place if the unbalanced weight overcomes the friction of the movement. . . . The instant an oil particle (migrating in water sediments) reaches a series of openings larger than those surrounding it, it stops and remains there indefinitely, as long as these surrounding openings are less than 0.1 mm. All sandstones are irregular and a series of openings larger than 0.1 mm. is never very extensive.

Mr. Mills has by his experiments excellently shown the effects of gravitation and current sorting of oil and water where the sand grains range from 0.5 to 6 mm. These results can not be considered applicable to the accumulation and arrangement of oil and water in oil sands except in unusual cases, since the average sand grains in most oil producing sands are approximately 0.2 mm. in diameter. Capillary resistance in sand bodies with grains of that size becomes so strong as explained in the previous literature that practically all gravitation and current sorting is obliterated.

ALEX. W. McCOY.

BARTLESVILLE, OKLAHOMA.

REVIEWS

The Ore Deposits of Utah. By B. S. Butler, G. F. Loughlin, V. C. Heikes and others. U. S. Geological Survey, Prof. Paper No. 111, 672 pages, 57 plates and 74 figures. Washington, 1920.

To write an adequate monograph on the ore deposits of one of our great metal-producing states is indeed a formidable undertaking, but one which promises rich results both in practical and scientific directions. For many years the authors have studied their state, its geology, its mineral deposits and its production and none could be more competent to undertake this task. They have succeeded brilliantly—even if the volume is a trifle ponderous with its 672 pages—and the miner and the geologist who have anything to do with Utah will rise up and call them blessed. The book is really more than the title indicates; it is in addition practically a geological treatise of Utah, omitting only the detailed discussion of the fuels and hydrocarbons. Mr. Butler has compiled a very valuable geologic map of the state on the scale of 1:76,923 or 12 miles to the inch. There is also a topographic map showing the 117 mining districts as well as power lines and power stations, further maps in color of the principal mining districts and a new, most interesting map of the Park City—Cottonwood Canyon region. The general chapter on history and production together with corresponding paragraphs regarding the individual districts have been contributed by Mr. V. C. Heikes, and there is no one who is better qualified to discuss the subject. The production by years, by districts, by metals and by kind of ores is tabulated and carefully reviewed. Incidentally meterology and water power is given space, the latter subject being treated by Mr. Herman Stabler.

Throughout, the geological features are adequately and fully discussed, much of the material being new and based on recent work by Messrs. Butler and Loughlin. Among this matter the description of the structural features of the Wahsatch Range should be mentioned particularly; its wonderful overthrusts are summarized and in part described in detail. Throughout much attention is given to the structural features which are also illustrated by a special map. An appendix with many plates by G. H. Girty illustrates the index fossils of the Carboniferous and Triassic rocks.

In connection with this there is also a chapter on physiographic de-

velopment which contains much of interest; it is pointed out for instance that the differential uplift of the Plateau Province is greater than that of the Great Basin. An explanation is given of the structure of the Basin Ranges which, however, like most of these attempts leaves something to be desired.

The chapter on mineralogy reveals that 200 mineral species are recorded in the state. Naturally the ore deposits are treated in great detail. The descriptions are in part critical compilations of earlier monographs and papers. To a large extent they are new, for Messrs. Butler, Loughlin and Heikes have spent much time in the reconnaissance of remote and little known mining districts, among which may be mentioned the Erickson, Promontory, Park Valley, Lucin, Dugway, Rush Valley, Ophir, Sierra Madre, Mount Nebo, Tushar, Gold Springs and a host of other localities. Special attention has been given to the Cottonwood-American Fork vicinity and to this description Mr. F. C. Calkins has contributed valuable material. Occasionally too much space has been given to detailed accounts of mines, but in most cases this refers to new districts not elsewhere described.

The general discussion of the ore deposits is contained on pages 150–215 and it cannot be commended too highly. On the whole it brings out overwhelming evidence in favor of the genetic association of most of the ores of Utah with processes of igneous intrusion. Some of the ore deposits are really pegmatitic in origin, *e.g.*, those of the Park Valley and Spring Creek districts. It is not impossible, however, that closer examination may differentiate between the pegmatite dike proper and its somewhat later mineralization. Contact metamorphism and vein phenomena are extremely closely connected in many districts of which Bingham (West Mountain) probably is the most illustrious example. Finally there are places like the Marysvale-Tushar and the Gold Spring and State Line districts where gold-bearing veins intersect effusive rocks and contain much adularia. The classification of the ore deposits is discussed from various viewpoints. Few of the deposits are of pre-Cambrian age. For the great majority the age is determined as Tertiary, ranging from the earlier to the later part of that period. The absence of Cretaceous rocks over a large part of the state makes exact age determination difficult, both for intrusives and ore deposits. The subject of alteration of rocks in connection with ore deposits is excellently presented and contains many stimulating suggestions.

Mr. Butler contributes to this volume two important generalizations to the science of mineral deposits. First, the relation of ore deposits to batholiths and laccoliths. It is shown that the latter are poor in ores because sealed off from the deep vents. It is shown that the batholiths deeply truncated by erosion are poor in deposits and of granitic nature;

while the "apically truncated" batholiths, near their roof, are rich in deposits and of monzonitic composition. The second generalization refers to the occurrence of sulphates in ore deposits. Their scarcity in deep-seated deposits is pointed out. They occur frequently in deposits formed at lower temperature. Mr. Butler believes that in the latter sulphur trioxide was more or less stable, while it could not exist in the high temperature deposits, and that probably the oxygen needed for SO_3 was contributed by the reduction of ferric to ferrous compounds.

The report contains also, in its general part, a discussion of the oxidation of ores and enrichment by descending waters.

The reviewer is supposed to criticize and point out the defects in the work under discussion. The present reviewer candidly admits that he can find little to criticize and a great deal to admire. He realizes the tremendous amount of patient work involved in the preparation of this volume and fears that the eight hour law has been seriously violated by its authors. Let us hope that the Geological Survey may find it possible in the future to prepare similar reports from other Western States, for such reports would meet cordial reception and would contribute to the general appreciation of the work of the organization.

WALDEMAR LINDGREN.

MASS INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.

A Text Book of Geology. Part I: Physical Geology. By LOUIS V. PIRSSON. Second Revised Edition. New York. John Wiley and Sons, Inc. 1920.

The essential features of a satisfactory text-book for elementary classes are clean-cut statements supplemented by carefully chosen verbal and pictorial illustrations and a choice of materials which will give the student possession of the fundamental facts, principles, and methods of the subject in such form as will arouse a desire to learn more than is given in the book. The beginner in geology is best served by a lucid presentation of the generally accepted teachings of the science. A text prepared for his use is not a suitable medium for the display of erudition, for the presentation of controversial matter, or for the airing of the author's peculiar views. The success of a writer of elementary treatises, like that of the teacher, is measured in terms of skill in exposition rather than by evidence of extensive research.

The first edition of Pirsson's "Physical Geloogy" met with general approval, for it revealed the experienced teacher. The time-worn truths were presented clearly, the matter brought up to date, and a reasonable balance maintained between the subdivisions of the subject. The chapters on Volcanoes, Igneous Rocks, Sedimentary Rocks, Metamorphic

Rocks, Fractures and Faulting, and the treatment of chemical, mineralogical and petrographic aspects of geology were especially commended. The chapters: The Ocean and its Work and Ice as a Geological Agency likewise showed an improvement on existing texts.

In respect to the origin and development of land forms the statements and discussions in the first edition revealed an unfamiliarity with the progress made during the past quarter century and led to much unfavorable comment. Some of the reviews were needlessly unsympathetic and failed to recognize the author's deliberate intention, as stated in the preface, to minimize physiography. Unfortunately the commendable effort "to preserve a more even balance," resulted in misplaced emphasis and misleading statements out of harmony with the teachings in most colleges and secondary schools.

The revised edition preserves the good features of the original with an improvement in diction and the elimination of minor defects in statements and illustration. In respect to physiography and mountain building the revision is fundamental. The changed viewpoint regarding physiography is shown in the elimination from the preface of the mild aspersion on students of land forms, a lessened emphasis on wind corrasion, a clearer recognition of the processes and meaning of river work and an attempt to give a proper place to the time factor in topographic development. The chapter on Mountain Ranges has been much improved by rewriting and by the inclusion of a discussion of complex mountains, of thrust faulting as applied to the Alps and of a more modern treatment of mountain form resulting from cycles of erosion.

The revised edition strengthens the position of Pirsson and Schuchert's "Text-Book of Geology" as a standard work for beginning classes, especialy when preceded by courses in chemistry and mineralogy. In the reviewer's opinion this book as well as its competitors would increase an interest in geology by pointing out practical applications and simplifying the discussion of ore deposits.

HERBERT E. GREGORY.

SCIENTIFIC NOTES AND NEWS[1]

MILLARD K. SHALER, mining engineer, of Brussels, left there in October for a six months' inspection trip to the Belgian Congo.

WALDEMAR LINDGREN, professor of geology in the Massachusetts Institute of Technology, has been retained by the Federal Company, in connection with the pending apex litigation between the Federal Mining & Smelting Co. and the Hecla Mining Co.

JOHN A. BURGESS resigned recently as general manager for the United Eastern Mining Company of Oatman, Arizona, and has opened offices as consulting mining engineer and geologist at 648 Mills Building, San Francisco, California.

ALFRED W. STICKNEY, geologist, is now safely out of Russia and was in Riga.

E. W. SHAW has returned to New York from Bolivia, where he was engaged in oil geology.

M. R. CAMPBELL, of the U. S. Geological Survey, inspected coöperative work in the coal fields of Wise County, Va., in November.

ALBERT W. GILES, associate professor of geology at the University of Virginia, has spent the last two field seasons in investigating the coal resources of southwest Virginia. The work has been carried on under the auspices of the Virgina Geological Survey in coöperation with the U. S. Geological Survey.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

H. G. FERGUSON, of the U. S. Geological Survey, has just returned from a month's vacation in the West Indies.

GEORGE I. ADAMS is in Washington, having recently returned from China.

ELMER H. FINCH AND MAX W. BALL, geologists of the Matador subsidiary of Royal Dutch-Shell Oil Co., recently accompanied President W. Van Der Gracht of Roxanna Oil Co. to the oil fields of Grand County, Utah.

W. A. TARR, after spending the summer at geological work for the Carter Oil Co. in northern Montana, has returned to his duties at the University of Missouri.

L. C. GRATON, consulting geologist, of Cambridge, Mass., left for Peru in October. He will be away from the United States for about six months.

D. F. HEWETT has returned to Washington after making an examination of the Crimora Mine in Virginia, for the U. S. Geological Survey.

GEORGE H. GARREY, consulting engineer and geologist of the Tonopah Belmont Co., after spending several months in the East, has now returned to Tonopah, Nevada.

WILLET G. MILLER, provincial geologist for Ontario, and Thomas W. Gibson, Deputy Minister of Mines, recently visited the mining districts of northern Ontario.

C. W. KNIGHT, assistant provincial geologist, Ontario Bureau of Mines, has been in charge of the geological examination of the Bourkes area along the L. & N. O. Ry.

G. F. LOUGHLIN, geologist in charge of the division of mineral resources, U. S. Geological Survey, recently visited the Leonard Mine in Butte, and the Survey offices at Salt Lake City, Denver and San Francisco, and has now returned to Washington.

F. M. VAN TUYL, who was examining oil lands during the summer months, resumed his duties in October, as head of the department of geology, at the Colorado School of Mines, Golden, Colorado.

CARL O. LINDBERG, mining engineer, of Los Angeles, Cal., sailed early in November for Bolivia, where he will be until the middle of January.

THE Hoover offices announce change of location on December 1, 1920, from the Mills Building to the Balfour Building. San Francisco. The offices include Herbert Hoover, Theodore Hoover, Oroville Dredging Co. Ltd., Sunset Engineering Co., Leonesa Mines Ltd., Pato Mines Ltd., James M. Hyde, David McClure, and H. W. Turner.

PAUL PAINE, of Tulsa, Oklahoma, is lecturing at Massachusetts Institute of Technology, on oil and gas production.

J. A. DRESSER, who investigated the resources of the Peace River district during the summer for the provincial government of British Columbia, returned to Montreal in October.

BULKELEY WELLS, of Denver, and George M. Taylor, of Colorado Springs, have been appointed to the committee of Colorado Metal Mining Association to coöperate with those trying to readjust relations with the management of Colorado School of Mines.

WILBUR L. MOODY, geologist for the Associated Oil Company and the Southern Pacific Company, was killed in an automobile accident near Fresno, California, last October.

L. SALAZAR SALINAS, director of the Geological Survey of Mexico, was in Washington and New Haven recently, studying the methods and organization of the U. S. Geological Survey.

F. A. BLAKESLEE, of the Institution of Mining and Metallurgy, London, has been in California, recently.

C. M. WELD, consulting mining engineer, of New York City, has moved his offices from 66 Broadway to 2 Rector Street.

W. J. LORING has retired from the firm of Bewick, Moreing & Co.

H. S. WEIGALL has been transferred from the Seoul Mining Co. in Korea to general managership of the Taio Gold Mining Co., in Fukuoka-ken, in Japan.

W. M. THAYER, formerly professor of geology at the Ohio Mechanics Institute, has resigned, and is now engaged in private consulting work in oil and mining geology at Cincinnati, Ohio.

F. L. RANSOME has left Washington for several months' field work in the Oatman and other districts in Arizona.

WALTER HARVEY WEED has severed connection with Harris and Co., of 25 Broad Street, New York. His present addresses are 29 Broadway, New York, and Tuckahoe, New York.

OLAF P. JENKINS has returned to Pullman, Washington, as assistant professor of economic geology in the State College, having spent the last year with the Sinclair Exploration Company, as chief geologist in Alabama.

FRED B. ELY is making a geologic survey for oil and gas in Coahuila, Nuevo Leon, and Tamaulipas, in Mexico.

EUGENE STEBINGER, of the U. S. Geological Survey, has returned from Bolivia, but is still on leave.

C. W. PURINGTON, mining engineer, has returned to Hakodate, Japan, from the Sakhalin and Okhotsk districts. His address is now 5 Sodomsky Pereulok, Vladivostok, Russia.

RAGNAR LIDEN, geologist of the Swedish government railroad, is studying the clay of the Cobalt district, Ontario, in connection with railway construction.

P. K. LUCKE, consulting mining engineer, of Mexico City, expects to return to Mexico at the end of December.

DOUGLAS R. SEMMES, professor of geology at the University of Alabama, has resigned, to become Assistant Chief Geologist of the Compania Mexicana de Petroleo, "El Aguila," and will

be located permanently at the company's headquarters in Tampico.

FRANK L. HESS, who went to South America last December, has returned to Washington.

V. DOLMAGE, of the Geological Survey of Canada, recently completed field work that makes possible a geologic map of the west coast of the island of Vancouver, B. C.

J. D. MACKENZIE has succeeded Charles Camsell, now Deputy Minister of Mines, in charge of the British Columbia office of the Geological Survey at Vancouver.

GILBERT H. CADY, formerly with the Geological Survey of Illinois, has returned from a year spent in professional business in the Far East, and has been appointed professor and head of the department of geology of the University of Arkansas. He also becomes State Geologist of Arkansas.

FRED B. ELY, of Fort Worth, Texas, is leaving for a stay of several months in Mexico, where he will examine an area for its possibilities in oil and natural gas.

E. S. LARSEN recently returned to Washington, after examining contact-metamorphic tungsten deposits near Portland, Oregon.

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